NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

REPRESENTING URBAN CULTURAL GEOGRAPHY IN STABILIZATION OPERATIONS: ANALYSIS OF A SOCIAL NETWORK REPRESENTATION IN PYTHAGORAS
by
Thorsten Seitz
June 2008
Thesis Advisor: Susan M. Sanchez
Second Reader: Jonathan K. Alt

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** June 2008	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE Representing Urban Cultural Geography in Stabilization Operations: Analysis of a Social Network Representation in Pythagoras			**5. FUNDING NUMBERS**
6. AUTHOR(S) Thorsten Seitz			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) Army Training and Doctrine Command, Monterey			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

Civilian human behavior representation is the most significant gap in representing political, military, economic, social, information and infrastructure aspects of the operational environment in urban operations. We consider three analytical models for different aspects of population dynamics, and explore whether they can be implemented in the Pythagoras 2.0.0 agent-based combat simulation software. These analytic models are an attitudinal effect model, a social network model, and an economic model.

This study shows that the transfer of simple analytic models into an advanced simulation software platform can bring unpredictable difficulties. A detailed investigation reveals the strengths and weaknesses of this advanced software, and shows that the current version of Pythagoras is not capable of adequately mapping all three human behavior models. The thesis recommends code changes to overcome these limitations and points out ways to improve Pythagoras' ability to represent human behavior, so it can be used by the U.S. Army and Marine Corps for more sophisticated analyses of stabilization operations. The ultimate goal is to provide decision makers with tools to help them make better decisions regarding stabilization operations and other issues critical to global security.

14. SUBJECT TERMS Stabilization Operation, Pythagoras, TRAC-MTRY, Urban Cultural Geography, Social Network Representation			**15. NUMBER OF PAGES** 125
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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REPRESENTING URBAN CULTURAL GEOGRAPHY IN STABILIZATION OPERATIONS: ANALYSIS OF A SOCIAL NETWORK REPRESENTATION IN PYTHAGORAS

Thorsten Seitz
Commander, German Navy

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
June 2008

Author: Thorsten Seitz

Approved by: Susan M. Sanchez
Thesis Advisor

Jonathan Alt
Second Reader

James N. Eagle
Chair, Department of Operation Research

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ABSTRACT

Civilian human behavior representation is the most significant gap in representing political, military, economic, social, information and infrastructure aspects of the operational environment in urban operations. We consider three analytical models for different aspects of population dynamics, and explore whether they can be implemented in the Pythagoras 2.0.0 agent-based combat simulation software. These analytic models are an attitudinal effect model, a social network model, and an economic model.

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LIST OF KEYWORDS, SYMBOLS, ACRONYMS, AND ABBREVIATIONS

AOR	Area of responsibility
CC	Color Change
DIME	Diplomatic, informational, military, and economic
GUI	Graphic User Interface
GWAT	Global War Against Terrorism
HBR	Human behavior representation
HN	Host Nation
HQ	Headquarter
I	Insurgency
NATO	North Atlantic Treaty Organization
NG	Northrop Grumman
NGO	Non-Governmental Organization
NOLH	Nearly Orthogonal Latin Hypercube
OE	Operational Environment
OPINFO	Operational Information
PM	Pythagoras Manual
PMESII	Political, military, economic, social, information and infrastructure
RUCG	Representing Urban Cultural Geography
S&R	Stabilization and Reconstruction
SF	Stabilization Forces

SFOR	United Nation Stabilization Forces in Bosnia and Herzegovina
SME	Subject matter expert
SO	Stabilization Operation
TRAC-MTRY	U.S. Army Training and Doctrine Command Analysis Center, Monterey
UN	United Nations
USA	United States of America
USMC	United States Marine Corps

EXECUTIVE SUMMARY

Civilian human behavior representation is the most significant gap in representing political, military, economic, social, information and infrastructure (PMESII) aspects of the operational environment in urban operations. Other identified gaps are the lack of organizational and social models, as well as inadequate or non-existent data collection, knowledge acquisition, and behavior representation methods.

This thesis in is support of the U.S. Army Training and Doctrine Command Analysis Center - Monterey (TRAC-MTRY)'s project on representing urban cultural geography. The objectives of this project are:

- to gather subject matter expert input from the fields of human behavior, sociology, and international studies;
- to develop data sets and algorithms to represent civilian behaviors that account for cultural influence in non-traditional warfare; and
- to develop models and code to represent these behaviors for stability operations.

TRAC-MTRY decided to simultaneously conduct two different approaches to reach the objectives. One approach is the development of a completely new discrete event simulation. The other is the basis of this study, and involves using an existing simulation tool. Pythagoras is the chosen tool because it is government-owned, open-source software and has the ability to be modified and enhanced. It was recently enhanced by the developer, Northrop Grumman, to remove some of the restrictions and limitations in its abilities to accurately map some sorts of human behavior.

The purpose of this study is threefold:

- to test the beta version of Pythagoras 2.0.0 to eliminate potential "bugs" and demonstrate that the software is capable of mapping human behavior in a stabilization operation according to three underlying simple analytic models;
- to build a generic model of a population subject to a stabilization operation and combine all three theoretical models to represent human behavior during this operation; and

- to identify appropriate ranges for key input parameters and analyze the results of various simulation runs.

The study explores the capability of Pythagoras 2.0.0 in modeling civilian populations by implementing simple analytic models for different aspects of population dynamics so their interaction can be explored. It provides a model methodology for represent human behavior and points out the strengths and weaknesses of this advanced software. In addition, it provides recommendations for further code changes which will remove some of the remaining limitations.

The three underlying analytical models for the simulation model are provided by Professors of the Naval Postgraduate School and are called

- the Attitudinal Effect Model,
- the Social Influence Model, and
- the Model of Insurrection.

Color is the feature in Pythagoras that expresses the agent's affiliation. The measure of effectiveness in this model is the agent's attitude towards the Host Nation. This attitude is expressed in blue; one of the three colors red, green, and blue which are implemented in Pythagoras to show the simulation run on the screen.

For this study, a purely generic model is developed in order to test the enhancements and new features of Pythagoras 2.0.0. All variables and parameters are arbitrarily chosen. The objective is not to build a realistic representation of a particular stabilization operation, but instead to evaluate the new software, to fix errors in the code and to verify the developed idea of representing human behavior.

The new software release has ten attributes that can represent a human's core beliefs, and attribute changers can now be used with weapons, terrain, or communications devices. We define four attributes for "Attitudinal Model" in this study, representing the core beliefs Religion, Infrastructure, Security, and Economic Security. With the built-in "Attribute Changer" device, the values of these beliefs can be changed, and because a change in a belief will alter a human's behavior, this should consequently change the value of an agent's blueness. There is no means in Pythagoras 2.0.0 to automatically change the blue value when an attribute value changes, so we tie these two together. In our model, a sufficient amount of change in the attribute values is responsible for a change in an agent's color status. Not all core beliefs have the same importance for a person, so we also introduce the concept of weighted attributes. This concept takes care of these differences and changes the attitude of an agent depending on his weighting of his core beliefs.

Participating in social networks depends on the attitude of a person. Therefore we establish a social network representation that allows an agent to talk to people with the same attitude. In accordance with the "Social Influence Model," talking to people means influencing them and being influenced by them. Thus the communication devices an agent possesses in the model are equipped with attribute changers, and communicating agents influence each other. Depending on his current color status, an agent can take part in several different networks at the same time. For example, his social networks might represent his family connections, his tribe connections, and a Host Nation friendly environment.

The "Model of Insurrection" explains a simple production economy. The income of a member of the population depends on the part of the economy he takes part in. These components are represented in the model as a production sector, a soldiering sector, and an insurgency sector. These sectors are implemented as different terrains; each terrain stands for a different economic sector and possesses different economic properties.

The study shows that there are some aspects of human behavior in stability operations Pythagoras 2.0.0 clearly can represent, but that there are aspects that cannot be realized without substantive changes to the software.

Because Pythagoras is a combat model, it can easily represent all parts of a stabilization operation that are related to any kind of military actions. Patrolling areas, hunting down terrorists, terrorist attacks, and so forth are easily to model and this part of the attitudinal model is modeled well. Even global actions like mass media or taxes can be modeled and analyzed, no matter if the entire populace is under this influence at the same time or only parts of it in different locations. So all influences from the outside acting on a single agent, a group of agents, or all agents at once can be mapped.

But there are other fields of a stabilization operation and human behavior that are not easy to map. We determine in this study that it is not possible to implement an effective social network representation or a simple production economy with the current version of Pythagoras 2.0.0. The analysis of the processes in the social network representation shows the errors between the calculated true values of influence transfer through the network and the observed values are as high as 70%; these are structural errors from the software implementation and they cannot be eliminated. Accordingly, a list of recommendations for code changes that can enhance the software's capabilities to represent human behavior are provided. These have been shared with to TRAC-MTRY and Northrop Grumman to assist them in planning for further Pythagoras developments.

Human behavior and societal dynamics are far too complex to be adequately represented by a single analytic model. The approach in this study is to combine several different models: three simple analytic models of specific aspects of human beliefs or behavior, along with a stochastic simulation model that can capture some of the richness of the operational environment and the mutual interactions among diverse sets of agents. This study shows that the transfer of simple analytic models into an advanced simulation software platform can bring unpredictable difficulties.

The results and findings show a way to enhance the capabilities of Pythagoras 2.0.0, so the software could be used by the U.S. Army and Marine Corps for more sophisticated analyses of stabilization operations. But they also demonstrate that it might be better to use more than one simulation software platform—along with more than one version of any component analytic models—to represent and predict human behavior.

Finally, this study shows that experimental design is a valuable tool during model development. It allows the analyst to explore a wide variety of situations and identify those that need to be investigated in greater detail. In the end, this will help the decision maker to come up with better decisions regarding stabilization operations and other issues critical to global security.

ACKNOWLEDGMENTS

First I want to thank my family, my beloved wife Doris and my children, Sebastian and Ricarda, for giving me every day during these studies love, support and understanding. Without their tolerance and help I would never have brought this thesis to an end.

Special thanks to my thesis advisor Susan Sanchez. She guided me with patience and knowledge and brought me always back on track. Thanks to my second reader Major Jonathan Alt, who asked the most valuable questions.

This thesis would not be possible without the support by Ed Bitinas from Northrop Grumman and his crew, who fixed the bugs we found wherever possible and ensured continuous development of the model. Not to forget the team of TRAC-MTRY, especially Leroy (Jack) Jackson and Gerald (Jerry) Pearman, who helped me with my first steps in Pythagoras.

A special "thank you" to Major Todd Ferris, who developed with me the model in uncountable hours in front of computers and chalkboards, for his ideas and willingness "to think the unthinkable", so we could come up with a great solution.

Finally thanks to all not mentioned for continuous support and deep friendship.

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I. INTRODUCTION

> NATO's experience in Afghanistan confirmed the need to upgrade NATO's 'software' and 'hardware' required for post-conflict stabilization…transforming for stabilization operations is not 'just' a new capability initiative, … it is about developing a 'new mission model' that successfully integrates the Alliance's actions with those by international actors. To that end, we need to improve our processes to better anticipate all aspects of stabilization operations and genuinely support civil-military interaction.
>
> **Jaap de Hoop Scheffer**, *NATO Secretary General*, June 2005

A. REPRESENTING URBAN CULTURAL GEOGRAPHY IN STABILIZATION OPERATIONS

This thesis in is support of the U.S. Army Training and Doctrine Command Analysis Center - Monterey (TRAC-MTRY)'s project on Representing Urban Cultural Geography (RUCG). As laid out in greater detail in several briefs and papers of TRAC-MTRY, the main objectives of this project are

- to deliver a documented methodology and algorithms to represent civilian populations and their behaviors in an urban environment during stability operations; and
- to innovate a modeling framework for cultures and societies in the context of non-traditional warfare, as well as the behaviors of the entities making up these populations.

Civilian human behavior representation (HBR) is the most significant gap in representing political, military, economic, social, information and infrastructure (PMESII) aspects of the operational environment (OE) in urban operations.

Other identified gaps are the lack of organizational and social models, as well as inadequate or non-existent data collection, knowledge acquisition, and behavior representation methods. To fill these gaps the RUCG project will

- gather subject matter expert (SME) input from the fields of human behavior, sociology, and international studies;

- develop data sets and algorithms to represent civilian behaviors that account for cultural influence in non-traditional warfare; and
- develop models and code to represent these behaviors for stability operations.

TRAC-MTRY decided to simultaneously conduct two different approaches to reach the objectives. One approach is the development of a completely new discrete event simulation. The other is the basis of this study, and involves using an existing simulation tool. Pythagoras is the chosen tool because it is government-owned, open-source software and has the ability to be modified and enhanced. Some unique capabilities that make Pythagoras potentially well-suited for the purposes of the RUCG project are:

- the use of desires to motivate agents into selected behaviors;
- the concept of affiliation (established by sidedness or color values) to differentiate agents into members of a unit, friendly agents, neutrals, or enemies;
- behavior-changing events and actions that may be invoked in response to simulation activities; and
- the enduring existence of traditional weapons, sensors, communication devices and terrain.

Because it is known that previous Pythagoras versions had some restrictions and limitations in their abilities to accurately map some sorts of human behavior, the developer of Pythagoras, Northrop Grumman (NG), was tasked to develop a new version and deliver it under the name Pythagoras 2.0.0.

The purpose of this study is threefold:

- to test the beta version of Pythagoras 2.0.0 to eliminate potential "bugs" and demonstrate that the software is capable of mapping human behavior in a stabilization operation according to three underlying simple analytic models;
- to build a generic model of a population subject to a stabilization operation and combine all three theoretical models to represent human behavior during this operation; and
- to identify appropriate ranges for key input parameters and analyze the results of various simulation runs.

TRAC-MTRY is well aware of the fact that testing a new software version, debugging it, and developing a model in parallel can be tedious and time-consuming tasks. However, until models are developed and explored it may not be possible to thoroughly test the software's performance. Thus this study was handed over to two students who should act as beta testers for Pythagoras 2.0.0, simultaneously build a model to test the capabilities of the software, and recommend necessary code changes after uncovering bugs (errors in the implementation). The testing and the model development described in this thesis were jointly done by the author and Major Todd Ferris, USMC.

B. STABILIZATION OPERATIONS

"Thirty years after the signing of the January 1973 Paris Peace Agreement ending the Vietnam War, the United States finds itself leading a broad coalition of military forces engaged in peacemaking, nation building"[1] and the Global War Against Terrorism (GWAT). For the armed forces of the United States of America (US), the North Atlantic Treaty Organization (NATO), or the forces assigned to the United Nations (UN), it is generally easy to fight a conventional war and win it without major losses. This can be seen in the recent past on the Balkans, the first Gulf War, Gulf War II, or in Afghanistan. With the most powerful and modern weapon systems ever, a modern symmetric war can be accomplished very quickly—lasting only a few weeks. But the end of the conventional fighting is not the moment the hostilities actually end, it is just the beginning of a new phase that may cause more troubles and require greater efforts than the fighting itself. The phase of rebuilding a beaten state, reestablishing a government, bringing back normal living conditions to the people, etc., is more challenging and expensive than the war itself. In the four-phase operations definition of the U.S. Army, these so-called "nation building" efforts are called Phase IV operations and involve post-conflict stabilization and reconstruction (S&R) efforts [Chait et al., 2006].

After the Balkan War, NATO and US forces were confronted with peacekeeping and nation building in what was left of Yugoslavia. However, the nation-building and

[1] Robert R. Tomes, Relearning Counterinsurgency Warfare, 16.

peacekeeping discussions during that time rarely addressed counterinsurgency warfare, perhaps because these operations “during the 1900s did not confront a determined, violent insurgency.”[2] This changed dramatically. In Afghanistan and Iraq, the coalition forces have to face a well-organized and deadly insurgency. The aim of the insurgency is usually to overthrow the constituted government “through use of subversion and armed conflict.”[3] “Insurgents use a combination of actions that include terror, assassination, kidnapping, murder,”[4] and increasingly suicide bombing. Beside these actions, the insurgency typically also encompasses “multifaceted attempts to cultivate support in the general population,”[5] either by bringing discredit upon the current regime or by direct financial aid for the people. The promise “to end hunger or eliminate poverty may appeal” to various segments of the population[6] as well.

To counteract this new kind of insurgency, new methods have to be explored in the execution of stability and counterinsurgency operations. They require “an interlocking system of actions—political, economic, psychological, and military.”[7] It is no longer appropriate just to provide security; nowadays the stabilization forces have to provide all kind of needs of the population. Basic needs include food and water, reconstruction of infrastructure, establishing an educational system and last but not least developing the economy. The attitude of the population toward the Host Nation (HN) and the stability forces (SF) is the measure of success or failure. The challenge today is winning the peace, as well as winning the war [Nelson, 2006].

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[2] Robert R. Tomes, Relearning Counterinsurgency Warfare, 16.

[3] FMI 3-07.22, Counterinsurgency Operations, October 2004, Headquarters, Department of the Army, 1-1.

[4] Ibid., p. VI.

[5] Robert T. Tomes, Relearning Counterinsurgency Warfare, 18.

[6] FMI 3-07.22, Counterinsurgency Operations, October 2004, Headquarters, Department of the Army, p. 1-1.

[7] Robert T. Tomes, Relearning Counterinsurgency Warfare, 17.

C. TRIBAL ENVIRONMENTS

Stabilization forces are primarily focused on the local population [Nelson, 2006], therefore this study deals with the effects of stabilization operations on the population of the host nation. In modern Western states traditional hierarchies are hardly ever found, because individualism has dissolved the determining influence of familial or even tribemoderated structures. Decisions, both economic and socio-political, are not decided or influenced any longer through the supreme authority of the patriarch (e.g., father, village elder, or chief). Instead, the individual person stands in the center and is responsible for himself and his environment.

In some countries in the Middle East and Asia, the social evolution is in another state. Here one can still find hierarchical structures that are characterized by close familial bands and clan structures. These structures are still widespread, especially in countries in which the armed forces of the International Community currently carry out stabilization operations. These power structures, which exist parallel to a possible government, have great influence on the mood and the behavior of the populace. For a profound understanding how different measures are perceived by the population the knowledge of these social relationships is indispensable.

This chapter gives a more precise consideration of tribal, clan, and family structures, so to say hierarchical structures, in the Middle East, especially in Iraq.

The tribe is the loosest connection. “Most tribes are organized as unitary political entities, in which people share a common language and culture.”[8] But a tribe is not necessarily a lineage group. “Tribes may also be of mixed sectarian or ethic composition.”[9]

The tribal leaders’ direct influences on daily life's decisions make the tribal structure extremely important for stabilization operations. The word of the sheik is law. In Rawah, the security situation changed dramatically after the leader decided to support

8 Encyclopedia Britannica online. http://www.britannica.com/ebc/article-9381141

9 Iraq: tribal engagement lessons learned (Essay). *Military Review*, 01 Sep 07.

the host nation.[10] During this so-called "Anbar Awakening" the leaders, especially Sheik Sittar,[11] ordered the populace to support the Marines. This led to a sudden rise of volunteers for the security forces and other beneficial effects.

This demonstrates the importance of the regional hierarchies. To know them and to be able to influence them favorably is a key to the success of any one’s operations. Local leaders sometimes have a far greater influence on the atmospheric situation of the population than the central government, which may be remote both geographically and socially.

However, one must not overestimate the influence of a sheik or clan leader, even if they represent the link to other tribes or clans and perceive important tasks in the "inside politics" of the clan. In urban areas like Bagdad their influence is restricted because the social development of the population is comparable to Western major cities. That means an individual strikes his own decision orientated on his own advantage. Clan structures contribute little to the social and political decision-making processes.

“In Iraq, as elsewhere in the Arab world, persons are more trusted than institutions.”[12] However, the influence of sheiks and tribes differs from region to region. Therefore, SMEs should be consulted to determine the extent of this influence, and their expert opinion should supply guidance about appropriate values of variables for the analytical models mapped in Pythagoras.

D. MOTIVATION

In 2000, the United Nations Stabilization Forces (SFOR) in Bosnia and Herzegovina supervised the peace agreements for the former war area on the Balkans. A multinational team consisting of French, Spanish, Italian and German soldiers, led by the French forces with headquarter (HQ) in Mostar, patrolled their special areas of

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[10] Die Stadt, die den Terroristen kündigte, www.spiegel.de/politik/ausland/0,1518,druck-522333,00.html, last accessed 12 Dec 2007.

[11] Turning Iraq's Tribes Against Al-Qaeda, www.time.com/time/world/article/0,8599,1572796,00.html, last accessed 10 Dec 2007.

[12] Iraq: tribal engagement lessons learned (Essay) *Military Review*, 01 Sep 07.

responsibility (AOR) to interview refugees to gather their thoughts about their personal situations, SFOR soldiers, and the overall political situation.

The multinational forces practiced different policies in dealing with the inhabitants. The overall aim of all activities was force protection. For the French forces every action taken was considered under the sight if it is to protect directly the own forces or not. Humanitarian aid was not considered part of force protection because it helped the locals more than the soldiers. The German forces took another approach—they considered every humanitarian assistance activity as a powerful part of force protection. Sometimes stones were thrown at French patrols, but this never happened to German forces.

The German battle group had its AOR around Sarajevo where the headquarter was located. The German battle group had an imbedded reconstruction team that worked close together with Non-Governmental Organizations (NGO) to build houses, bridges, or sewage systems. The German S5 and his team supported schools by delivering small items like stoves, blackboards, books or toys, as well as their regular duties. German patrols not only provided security by pure representation but also helped the people by delivering food, clothes, and toys. Because they did not differentiate between the diverse ethnic groups, the German forces had a good reputation within the population. French soldiers never supported the inhabitants with daily needed items or repairs; they viewed force protection as driving around in armored vehicles and showing strength. However, the most important difference was that French forces never were neutral, but they always preferred the Serbs.

Another means of influencing the attitude of the population was the use of so-called Operational Information (OPINFO) teams. These teams were responsible for informing the inhabitants about the range of task of SFOR, preparing special actions, and gathering information from the population. Again, the French and German forces used totally different approaches. The French used OPINFO mainly to spy among the population; the German OPINFO delivered a weekly newspaper, operated a radio station, and supplied schools with material, e.g., for language courses. Daily work showed that the attitude of the population, which consists of Serbs, Bosnians, and Croats, strongly depends on the behavior of the SFOR soldiers.

Perhaps the most drastic example of the different standing of the troops in the French AOR was a demonstration in front of the French HQ. The demonstrators were angry about some decisions made by the government and SFOR in the last couple of weeks, and so they gathered at the entrance of the HQ. Nobody was sure if the situation would stay calm or if it would escalate to massive acts of violence. Therefore, the French leaders decided to call the German battle group to support the HQ protection. The German small tanks were located in the front row, face to face with the masses. When the atmosphere was close to exploding, the patrol leader took of his helmet and laid down his body armor and went alone to the leader of the demonstrators to talk to him. This behavior caused the leader to calm down his men, the situation cleared, and it came to no aggressiveness that day.

These examples show the importance of using the right measures to influence a population. Driven by this experience, the author is interested in building a model to investigate the sensitivity of a civil populace to a range of host nation and insurgent actions.

E. RESEARCH QUESTIONS

As mentioned before, the purpose of the study is threefold: beta testing the Pythagoras 2.0.0 modeling platform, building a model which maps three analytical models - an Attitudinal Effect Model that explains the change of a population's attitude over time, a Social Influence Model that explains how subpopulations influence each other, and a Model of Insurrection that explains the process in a simple production economy - into one simulation, and analyzing the results to find their sensitivity to various input parameters. Details of these models appear in Appendices A, B, and C, respectively. The following questions will be answered:

- What are the strengths and weaknesses of Pythagoras for modeling civilian populations?

- Does Pythagoras accommodate the theoretical models from the social arena relevant for modeling civilian populations?
- Does the composition of the population impact the effectiveness of blue force actions?
- How sensitive are the attitudes of the civilian populace to a range of diplomatic, informational, military, and economic (DIME) and insurgent actions?

F. IMPORTANCE OF THE STUDY

The study explores the capability of Pythagoras 2.0.0 in modeling civilian populations by implementing analytic models. It provides a model methodology to represent human behavior and points out the strengths and weaknesses of this advanced software. It provides recommendations for further code changes which will remove some of the remaining limitations, and it shows that experimental design can be a valuable tool during model development.

This thesis is an important step on the route to develop a model that is capable of mapping the behavior of a population in a stabilization operations and allowing analysts to investigate the sensitivity of a civil populace to a range of host nation and insurgent actions. As this modeling capability develops, it will become possible to predict the ranges of effects of various combined actions, depending on the composition of the population. Therefore, decision makers will have a tool to provide quantitative insights that help them find effective and low-cost ways to plan, change, and accomplish a stabilization operation.

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II. PYTHAGORAS

Pythagoras is an agent-based, time-stepped model, developed by Northrop Grumman, that incorporates fuzzy logic. It allows one to create autonomous, intelligent acting agents that can act and react based on multiple decision rules. The decision rules determine the specific appearance of an agent, they can be seen as variables. The modeler can declare these variables as constants (deterministic) or can define a tolerance around a mean which will be reset every time step by a random draw (stochastic).

In this chapter, the most important parts of the model implementation in Pythagoras are explained. The features, tabs and settings not described in detail in this chapter are necessary for the software to run, but do not directly support the model. For a deeper understanding of Pythagoras the reader is referred to the Pythagoras manual. [13]

In the process of developing the model, we were in close contact with NG and discussed code errors and made several recommendation for code changes. The last version used for this study was Pythagoras 2.0.0, revision 19, downloaded directly from the FTP server of NG.

A. BASIC IDEA

A purely generic model is used to find out Pythagoras' suitability for modeling human behavior and mapping the three analytical models. All input values (such as the sizes of the subpopulations, population distributions, effectiveness or fire rate settings, and so forth) are arbitrarily chosen to test the generally idea of the methodology. The basic idea is to express the underlying attitude of a subpopulation towards the HN in terms of its 'blueness.' A specific agent's 'blueness' can change as it is influenced by other agents or external events. In other words, changing the inner beliefs of an agent will change its visible attitude and actions.

[13] Pythagoras User Manual, Version 2.0, March 2008.

To underline the generic character of the model, the expression ‘playground’ is used to describe the area the model runs in, and not ‘battlefield.’ That should help the reader avoid direct comparisons of model ideas and outputs with events from the real world. Terms like ‘battlefield’ or ‘city’ could mislead the reader to think in categories this study is not intended to capture.

For this generic version of the model, all variables are kept deterministic to compare the results of the simulation runs with the pre-calculated results to find possible errors, either in the methodology or the software code. This is true for all settings in the model and should be remembered in the following.

Even though this model does not represent reality, some assumptions are made that, in fact, tie parts of the model to daily life experiences. For example, it is assumed that a member of a subpopulation that initially leans towards the HN lives in an area which is controlled by the HN and stays there as long as his attitude does not change. This is determined from observation that people leave an area when their fundamental beliefs or financial situation no longer match those of their neighbors. Other assumptions made will be explained in more detail in context as they are introduced.

B. NAMING CONVENTION

All names used for agents, weapons, attribute changers and other features are derived from (and therefore closely related to) the analytical models. To keep track of the subpopulations, terrorists, soldiers, the terrain they act on and the weapons they use, we use names that clearly identify the actors and actions. According to the attitudinal model “there are S subpopulations” which divide the entire population in smaller parts. These subpopulation could also be named tribe, family or what ever represents a (more or less) homogenous fraction of a population in reality. The names for the economic sectors, the Production_Force_EconomicSector, the Insurgency_EconomicSector, and the Soldiering_EconomicSector, are derived from the “Model of Insurrection” and explain the respective neighborhood.

For the convenience of the reader, in the following **agent** names are printed in **bold**, *weapon* or *influence* names in *italic*, and `attribute changer` names in `courier`.

For subpopulations, the attitude towards the HN is what defines the name. Consider a neutral subpopulation representing the Production Force (PF). A subpopulation that initially leans towards the HN could be called **PF_ILT_HN**. It is this subpopulation that, at simulation start, is more closely affiliated with the HN. Of course not all members of the working populace have a positive opinion of the government. A certain percentage is in opposition and initially leans toward the insurgents, and consequently this part of the PF population has the name **PF_ILT_I**. At the beginning of the simulation, based on the economic model, people with the same convictions live in the same neighborhood. Because there are three different kind of subpopulations in the model, there are three economic sectors. Their name indicates the opinion of the population living there.

This convention is used consistently through the entire model. An action initiated by the HN with a political machine perceived as good by a subpopulation is named *HN_PM_PG*. To change the populace's attitude we used attribute changers; the changer assigned to *HN_PM_PG* is called `HN_PM_PG.` An agent we need solely to implement the proper movement of civilian agents into different economic sectors is named **Z_PF_Leader_for_MovementOnly_199to220_LtoR** because he has no other tasks in the model. Tax rates assigned to specific economic sectors? `S_TaxRate` and `PF_TaxRate`.

The idea of equal names throughout the model to show the connection between different functions is demonstrated in Figure 1. Here, an agent possesses a weapon which possesses an attribute changer, all named HN_PM_PG_Duration; that is the naming convention in this study.

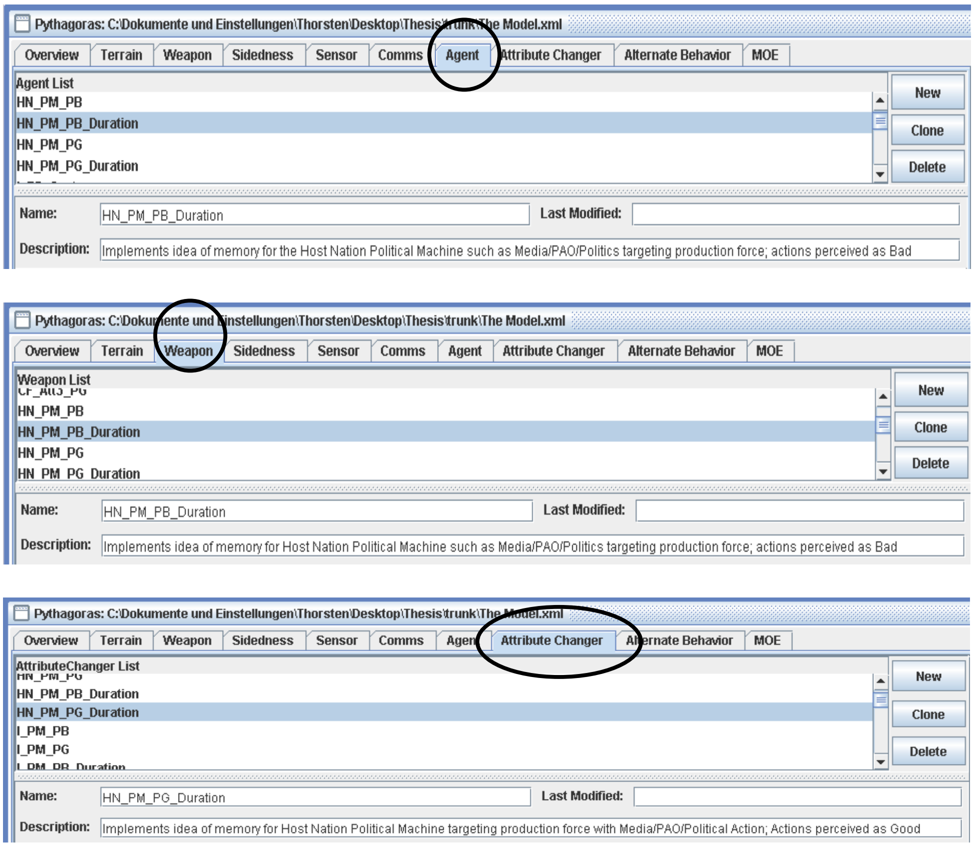

Figure 1. The Naming Convention

C. WEAPONS

Two different kind of weapons are used in the model: indirect weapons that represent global influences suffered by all agents on the playground, and direct weapons that symbolize actions taken by terrorists or HN soldiers. In accordance with the naming convention, the names clearly indicate what kind of action is assigned to the weapon.

Some basic settings are valid for both types, e.g., the effectiveness settings for all weapons used in this model are set to zero. Thus all weapons are non-lethal and are not supposed to kill the agent they are fired at. The idea is to use a weapon to transfer a change of attribute, therefore each weapon possesses an attribute changer with the corresponding name. The functionality of attribute changers is explained in detail in the paragraph "Attribute changers." The maximum engagement range defines the range over which a weapon can be deployed. Setting the ammunitions rounds to a high number makes sure there is enough ammunition available for the entire simulation. Again, the weapons are not supposed to kill, but for each time step a weapon is used, sufficient ammunition must be available to shoot and transfer an attribute change. The fire rate is tied to the idea how often a subpopulation is affected by a specific influence. A rate of 0.1428 stands for an influence which is active every seventh time step; this could represent a weekly newspaper or a weekly political gathering. Because everybody in a populace is under this influence—whether he has more sympathy for the HN, leans toward the insurgency, or is strictly neutral—the weapons target acts against every agent on the playground (Figure 2).

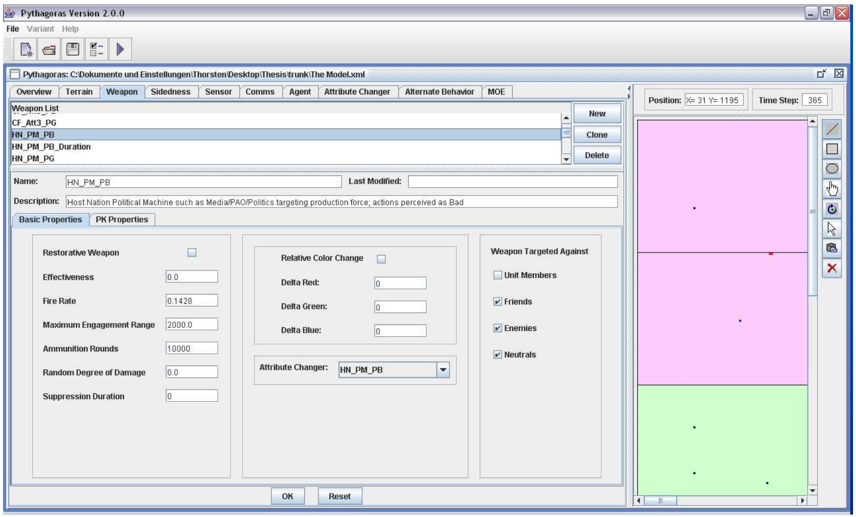

Figure 2. Basic Weapon Settings

For indirect weapons, which act as global influences over the entire playground, the Cookie Cutter Blast box on the PK Properties tab is activated (Figure 3). That means that all agents within the range of the weapon get the same amount of influence, no matter how far away they are from the center of the impact. With this setting all influential, globally-acting weapons can be located in the yellow area in the middle of the playground and are equally effective everywhere. In contrast, direct weapons are possessed by agent which attacks other agents and deliver a specific influence just to agents under attack, not globally to all on the playground.

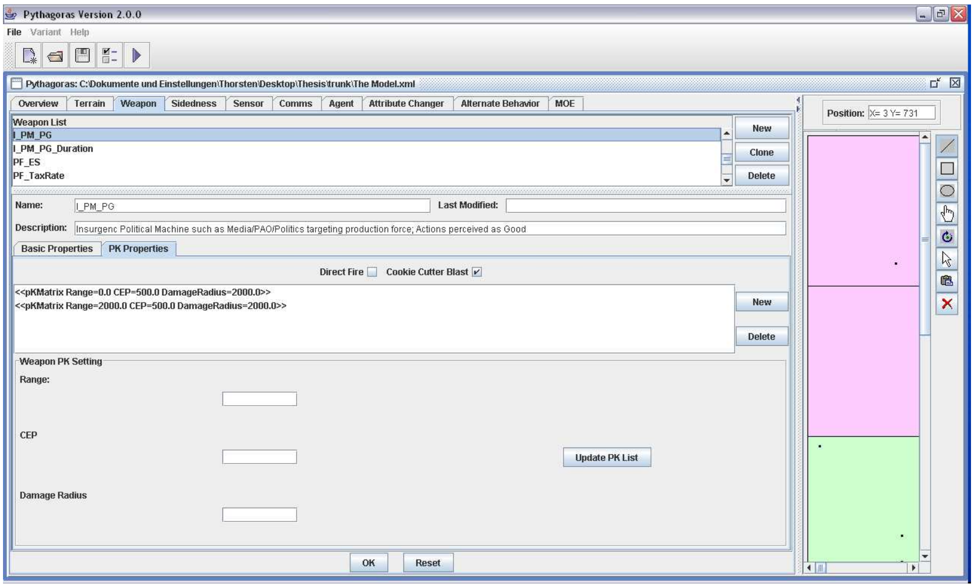

Figure 3. Indirect Weapon Settings

D. ATTRIBUTE CHANGERS

Pythagoras 2.0.0 has now ten attributes instead of only four in the older versions, and it is possible to give these attributes meaningful names. This is one of the software changes we recommended during this study, and now the modeler can express his thoughts more clearly. According to the basic idea of this model, the attributes are named after what we thought the main issues for a person living in an environment subject to a stabilization operation (SO) might be. Thus we called them Religion, Infrastructure, Security and Economic S(ecurity). We think that these attributes drive the perception of a population, and a change of these issues results in an overall change of attitude. E.g., a father who needs money to ensure the survival of his family has a certain opinion about the government. If the HN is able to improve the economy and provides Economic S(ecurity), perhaps by giving the father a well-paying job, it is natural that his opinion might change and make him view the government more positively. Conversely, he might turn towards the insurgency if the economy crashes and he loses his job.

Attribute changers are the machinery to accomplish these changes. A change is caused by an influence from the outside; attribute changers represent these influence.

There are several types of influences which act every day on a populace. No two are the same; they point to different issues with different power and different rates. Thus, an attribute changer can possess different values for each individual attribute. Each value is the amount by which a targeted agent's corresponding attribute value is changed. An attribute changer can be of four different types: Incremental, Absolute, Relative, or Multiplicative [PM, Changer Type, 13.5.2]. We use two types in our model: incremental changers with all influences that act on a subpopulation from outside (Figure 4), and relative changers for the influences transferred via the social networks.

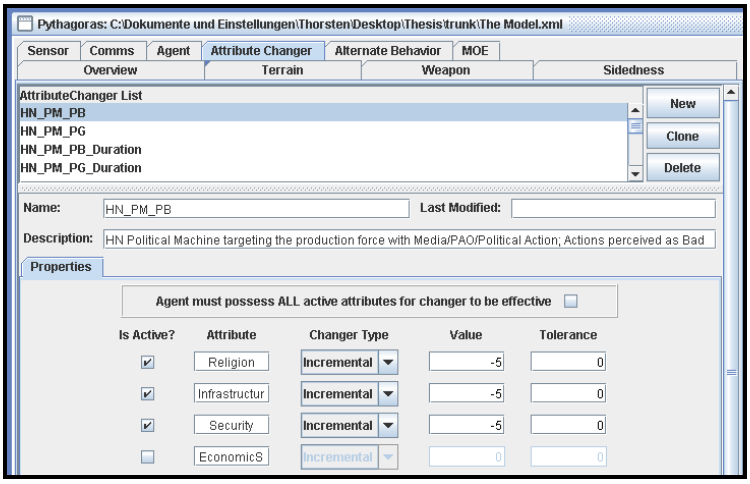

Figure 4. Incremental Attribute Changer

Attribute changers cannot act alone, but need actors that possess and use them. Therefore the changers are named consistently with the naming convention and are assigned to the respective weapons and agents.

E. COMMUNICATIONS

With the communications devices of Pythagoras we modeled the social network based on the social network model of Professors Krackhardt and Gibbons (Appendix B). Each comms device represents a different social network and the agents possessing this device participate in the network. Participating in a network means interacting with other agents on the same channel. Every social network has its own channel so that only members in the same social environment can talk to each other. Consequently, an agent which participates in more than one social network possesses more than one comms device.

There is one social network an agent always participates in—his family network. This network is the one an agent never loses, independent of his attitude towards the HN. The idea behind this implementation is that family ties are always active. Even if an agent has a developed a completely different opinion from his initial roots, a mother will always talk to him. All other networks depend on this attitude, and an agent can lose or gain network connections as time progresses. These comms devices allow two-way interactions so each agent can talk (i.e., send influence) and listen (receive influence). Therefore subpopulations can influence (and be influenced by) other subpopulations when some of their members are in social networks in both groups.

Family networks have a slightly different setup. To map the stronger influence a family leader might have on his family members, he has a one-way device for talking only. So he influences his family, but as usual in a patriarchal system, there is no feedback (Figure 5).

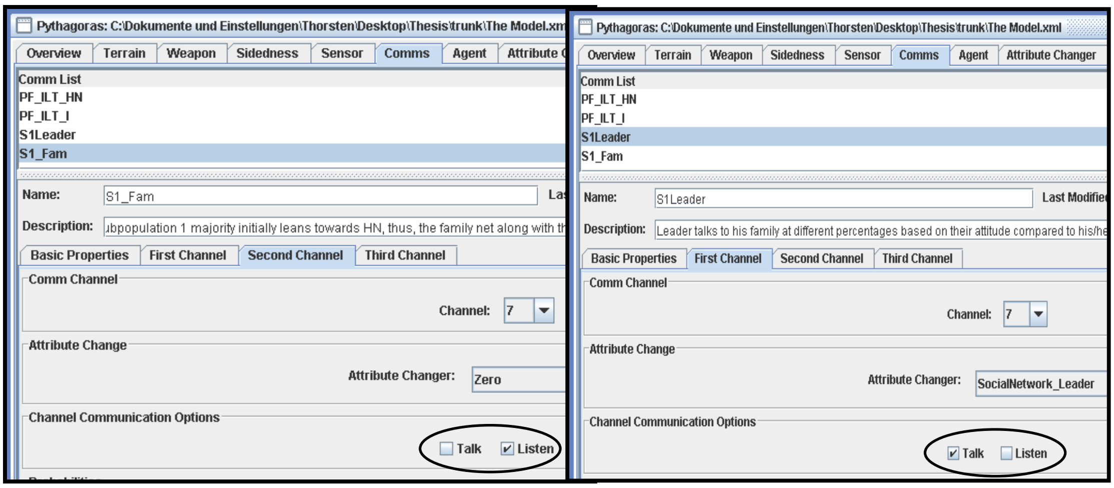

Figure 5. Family Network Settings

All communications that actively transfer influence through the network possesses an attribute changer according to the basic idea of this study. Receiving units like **S1_Fam**, which stands for a family of subpopulation 1, own a `Zero` changer because they do not have an active role on this channel in the network.

F. TRIGGERS

Triggers are the events that cause an agent to change his behavior [PM, Triggers, 12.27]. Two thresholds are always assigned to a trigger: an upper and a lower threshold. Whenever one of these is reached, a trigger is activated and the agent starts to act according to a new alternate behavior. We use triggers to force an agent to participate in a different social network once his blueness changes sufficiently. In the following, the term "a trigger trips" is used to explain the fact that a threshold is reached, the particular trigger is activated, and the agent acts according to the new behavior. Because an agent's behavior can depend on more than one event, there is a huge set of possible triggers. As Pythagoras is a time step model, and an agent can only be in one behavior at a time, the triggers are prioritized. That is, if two or more threshold are reached in the same time step, the trigger with the highest priority trips (Figure 6).

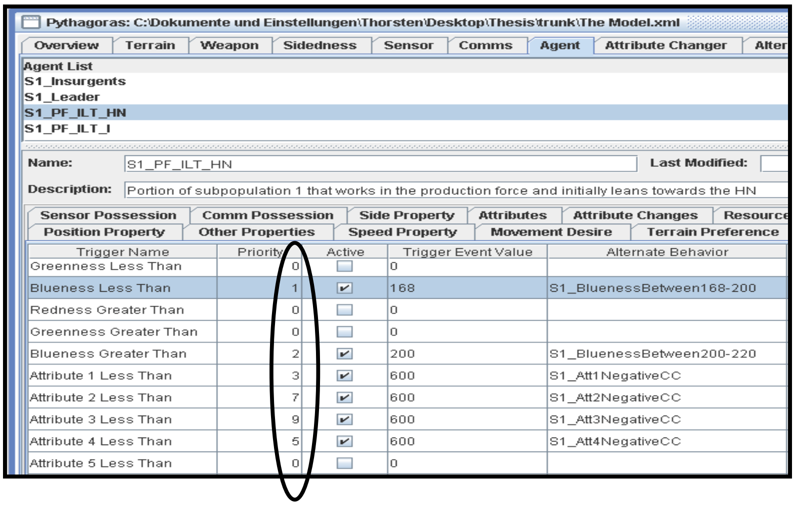

Figure 6. Trigger Set and Priority Setting

G. ALTERNATE BEHAVIORS

“Alternate behaviors are new behaviors that an agent will follow once a triggered event is activated” [PM, Alternate Behaviors 14.0]. An alternate behavior is typically different from the agent's initial behavior and thus it can represent a change in the agent's attitude towards the HN. The social network representation in this model is based upon alternate behaviors. Participating in a social network different than the initial social network means acting according to a certain alternate behavior. In an alternate behavior the settings of an agent can be redefined or the initial behaviors can be kept; we alter the communications devices to let an agent be part of the appropriate subpopulation (Figure 7). Once an agent has obtained different communication devices, an agent will not only talk to new people, he will also influence them and be influenced by them.

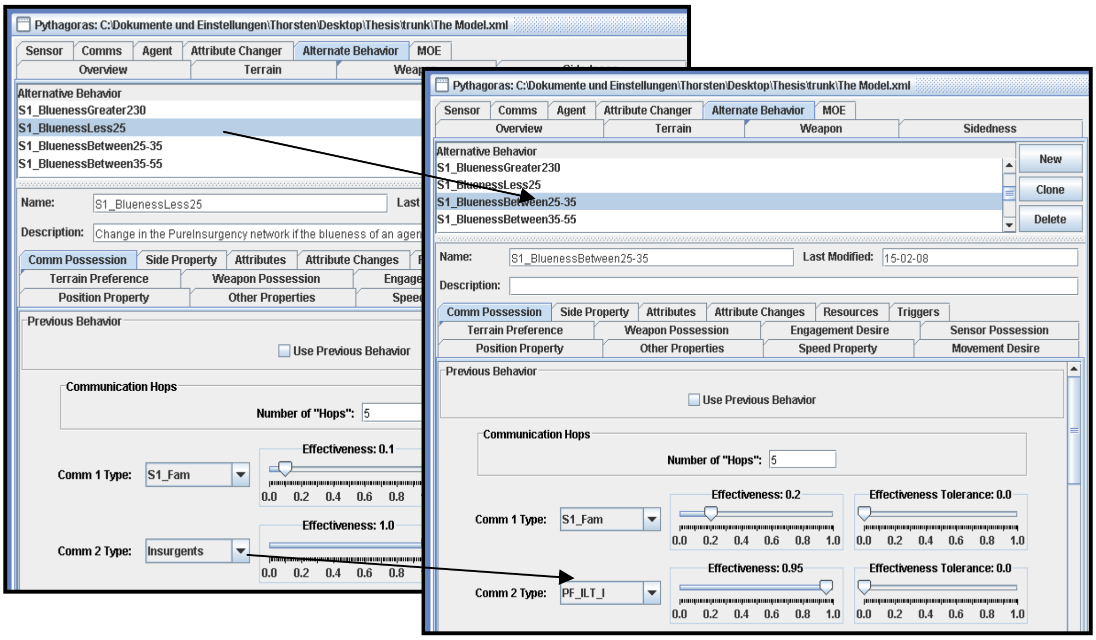

Figure 7. Alternate Behaviors – Social Network Representation

Another crucial alternate behavior we use in our model is the "color change" alternate behavior, responsible for providing an appropriate color change of agents.

III. ANALYTIC MODELS

A. ATTITUDINAL EFFECT MODEL

1. Synopsis

The theoretical background for this model is provided by Professor Jacobs et al. (2007) and explained in detail in the research paper "A Model for the Effect of Host Nation/Insurgency Operations on a Population" (Appendix A)

The basic idea is that different actions act on a homogenous subpopulation and, over time, change the attitude of this populace. The subpopulations do not take any actions in this model; only the actors, which can represent members of the Host Nation or the Insurgency, act against each other or against the subpopulations. The actions of either side are perceived as good or bad by the subpopulations, and therefore may cause subpopulations to change their attitude towards the host nation or the insurgency. Because no action is remembered indefinitely, there is a duration assigned to each action and, after a certain time elapses, the action completely fades out of the subpopulation's memory.

Every actor's action can be perceived as good or bad, depending on the initial opinion of the subpopulation. For example, if valuable infrastructure is destroyed during a terrorist hunting operation of HN troops, different parts of the populations may perceive this differently. The part of the population that leans towards the HN may perceive the overall action as "good" because it provides an increase in security. The part of the population which has sympathies for the insurgency may perceive this as "bad" because of the loss of infrastructure.

Subpopulations interact and exchange their views on diverse topics and therefore can also be seen as actors like the HN or the I. The attitude of a particular subpopulation can be influenced by actions taken by the other subpopulations.

A simplified version of the formula provided by Jacobs et al. (2007) takes the form

Attitude towards HN at time (t+h)	=	Attitude towards HN at time (t) due to HN and I actions		
	+	Attitude change towards HN at time (t, t+h) due to HN actions perceived as good	-	Attitude change towards HN at time (t, t+h) due to HN actions perceived as bad
	+	Attitude change towards HN at time (t, t+h) due to I actions perceived as good	-	Attitude change towards HN at time (t, t+h) due to I actions perceived as bad
	+	Attitude change towards HN at time (t, t+h) due to influence of other populations		

2. Pythagoras Implementation

The different parts of the attitudinal model that must be implemented in Pythagoras are all actions that are perceived as good by different subpopulations, all actions perceived as bad, durations for these actions, and interactions among subpopulations.

a. Globally Perceived Actions

An influence does not act permanently on a subpopulation, therefore a specific rate is assigned to each influence. This rate is represented by the fire rate of a weapon. An influence that is active every seventh time step has a Fire Rate of 0.1428. This could stand for a weekly newspaper, a political show on television, or the Friday prayers in a mosque (Figure 8).

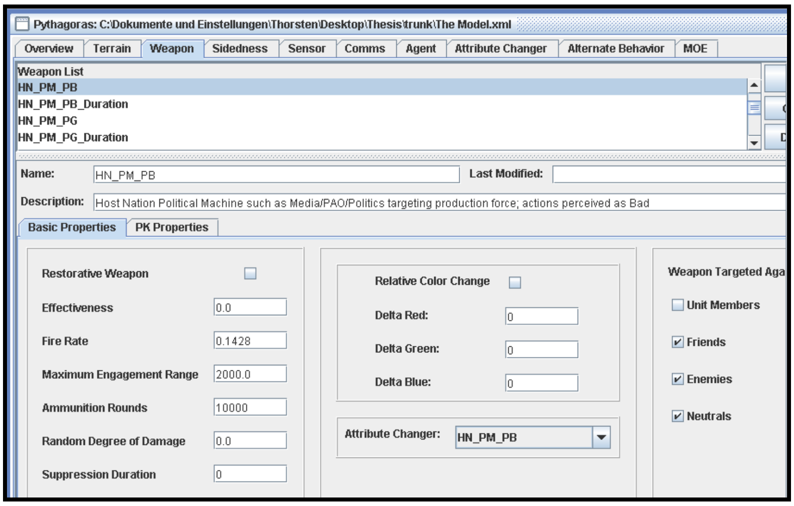

Figure 8. Implementation of a "Weekly" Influence

Because these kinds of actions influence not only a single agent but all agents on the playground, they are called *globally perceived actions*. An activated Cookie Cutter Blast Box on the Weapon - PK properties tab indicates that this is an indirect weapon that has an impact on all agents within range. As discussed in Chapter II, the effectiveness of the *HN_PM_PB* is set to 0.0, so this weapon is non-lethal. In this model, all weapons are non-lethal because they are supposed to represent influence rather than kill other agents. The machinery to transfer influence is an attribute changer. The values of negative five shown in Figure 9 shows that every time a weapon possessing the `HN_PM_PB` attribute changer fires, it reduces the attitudes Religion, Infrastructure, and Security by five for all other agents within range.

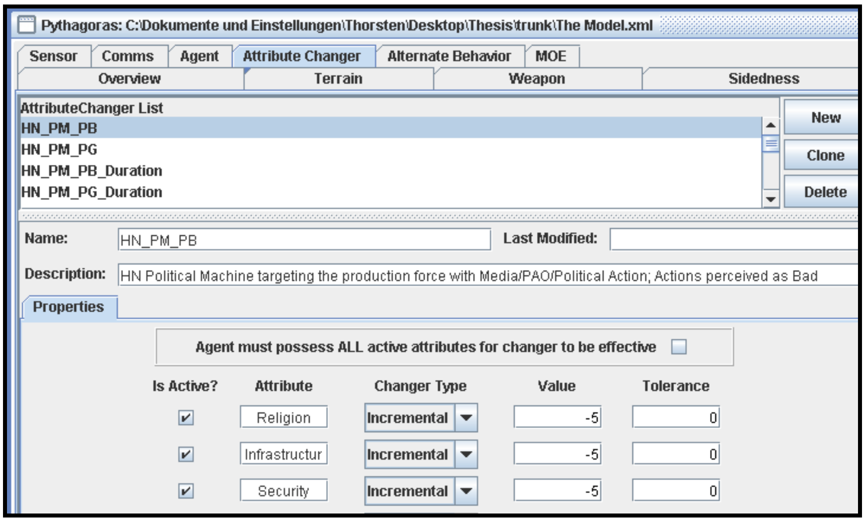

Figure 9. Amount of "Weekly" Influence

b. Memory Implementation

The analytical model of Jacobs et al. defines a duration for every action. During this time, an action is presumed to be active and have some influence; after this timeframe, it is forgotten. To implement this in the Pythagoras model, a duration-agent is installed. This agent is like a mirror image of an actor, the only differences are the rate it fires and the sign of the attribute value. The amount of attribute is the same as the amount of the actor. So the duration-agent just takes away the influence after a certain elapsed time. If an actor influences the population every third day, for example, a duration-agent may kick in every seventh day and take the same amount of influence away. So the population remembers the action for a specific period and then completely forgets it. Within this timeframe, the action is active and can be transferred through the social network. This sequence is shown in Figure 10. In accordance with the naming convention, the weapon and attribute changer share the same name as the actor, so parts belonging to each other in the model are easily to identify.

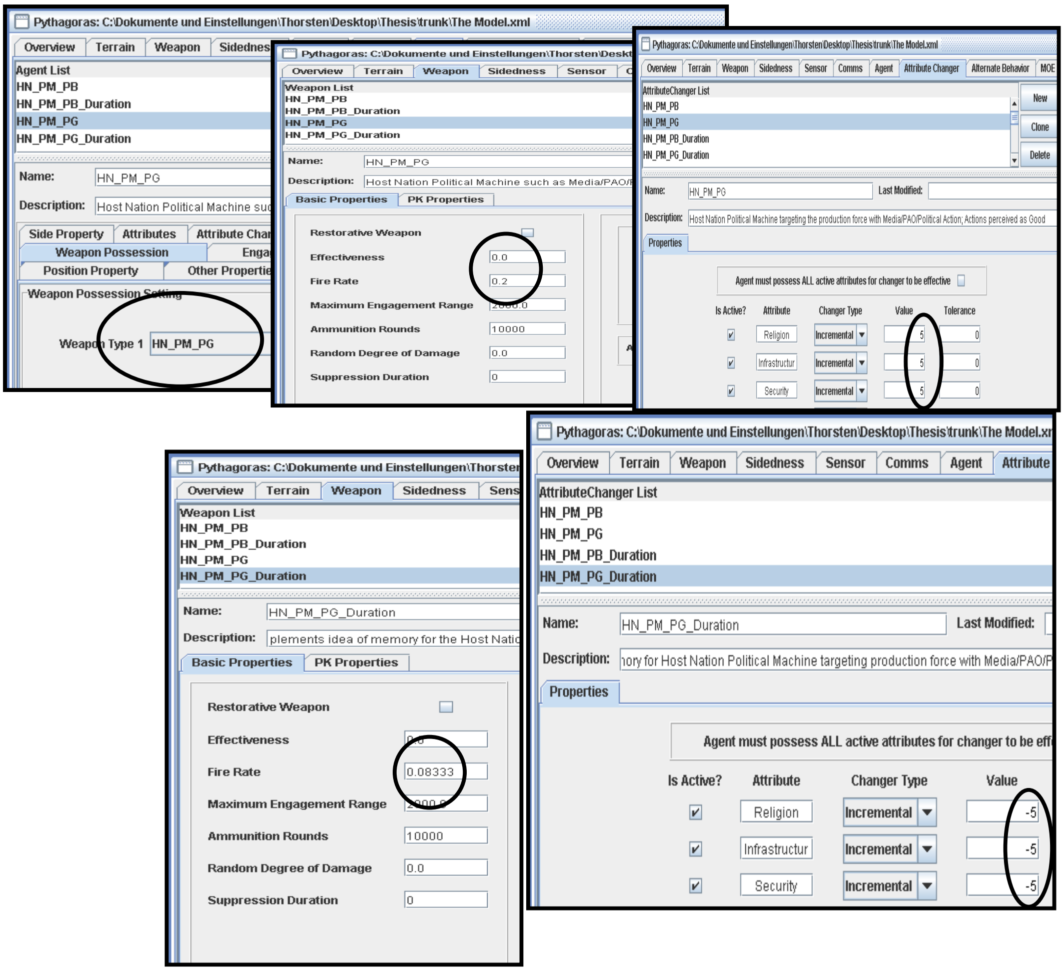

Figure 10. Memory Implementation for **HN_PM_PG**

This memory, or duration of an action, can only be implemented for globally perceived actions. Globally perceived actions are those which can be suffered by all agents on the playground simultaneously. Thus the weapons which are responsible for the delivery of these actions are indirect weapons with ranges that includes the entire playground. Only those agents who are influenced by an action are allowed to receive the negative amount of attribute change later on in the simulation in order to forget the action. Otherwise a subpopulation would forget something it never learned.

In summary, the duration rate is implemented as a globally acting indirect weapon with different rate and sign but the same amount of attribute change as the respective actor.

c. Non-globally Perceived Actions

Not all actions on the playground are perceived by all agents at the same time. It is somehow understandable that some actions influence all subpopulations in an area at once, while others do not. Actions like political decisions or the starting of a new power plant affect all subpopulations. Terrorist attacks or suicide bombings may initially affect only those persons nearby. Similarly, actions executed by actors of the HN may have differential effects: hunting terrorists down may affect some agents in the direct area of the operations, but inhabitants living far away may not even be aware of these activities. After a particular action, agents keep on moving on the playground and depending on the (random) simulation run, two involved agents may never come close again until the simulation ends. This is the reason that non-globally perceived actions are memoryless. In order to let the affected agent forget the action, either both agents must meet again and reverse the attack, or another attacker must deliver the negative amount of influence. To accomplish this, the second attacker must know about the original attack, including when it occurred and what was the influence. There is no way to map this kind of behavior in Pythagoras. So in contrast to globally perceived actions, non-globally perceived actions have no memory implementation in this model.

B. SOCIAL INFLUENCE MODEL

1. Synopsis

The influential model is based on a paper provided by Prof. Gibbons et al. (2007) for the RUCG project (Gibbons, Notes on Influence Models for Dynamic Settings, Appendix B). The outlined models are summarized in this chapter and form the basis for the social network representation in our model. Prof. Gibbons sketches a few versions of what she calls the fundamental influence model in social systems. Two of them, a diffusion model and a viscosity model, are not subject to further investigations in this thesis because they are based on Markovian states which can not be implemented in Pythagoras 2.0.0. For more details the reader is referred to Appendix B. The two other models are now described.

In a fundamental influence model, an individual has an attitude or is likely to engage in a behavior as a function of primarily attributes (age, sex, education, resources available, etc.) and social attributes (influence from others, contacts, competition, etc.). The first class of factors can be characterized in a first standard model as follows:

$$b_i = \mathrm{X}_{ik}\beta_k + \varepsilon_i\,, \qquad i = 1,\ldots,N$$

where

- N is the sample size
- k is the number of explanatory attributes
- b_i is the dependent variable of interest (attribute, behavior, performance) on the i th subjects
- X_{ik} is a matrix of k explanatory attributes for the i th cases (people)
- ε_i is the error term, where the ε_{i} are assumed IID

The magnitude (β_k) and the significance of the effect each of the k variables has on the dependent variable can be estimated using multiple regression techniques.

But the observations are not independent, because people influence each other. Social network models take into account such effects through a second model that takes the form:

$$b_i = \mathrm{X}_{ik}\beta_k + \rho_1 \mathrm{W}_{1ij} y_j + \varepsilon_i, \quad \varepsilon \sim \rho_2 \mathrm{W}_{2ij}, \quad i, j = 1,\ldots,N$$

where

- N is the sample size

- W_1, W_2 are $N \times N$ matrices that describe the extent to which each neighbor in the network affects each other
- k number of explanatory attributes
- $W_1 y$ describes the direct effects on a particular actor of all actors in the system
- W_2 term describes indirect effects by taking into account that the errors ε are not independent but auto-correlated
- ρ scalar parameter

For our model we take the ideas behind the influential models and map the effects of attributes using the communication devices and attribute changers.

2. Pythagoras Implementation

A social network basically depends on the interaction between the members of the network. Members of a social network in our model are the agents representing subpopulations, leaders of subpopulation, soldiers, or insurgents. The interactions between two agents or among a group of agents are modeled with communication devices, where each subpopulation has its own device to communicate with (Figure 11).

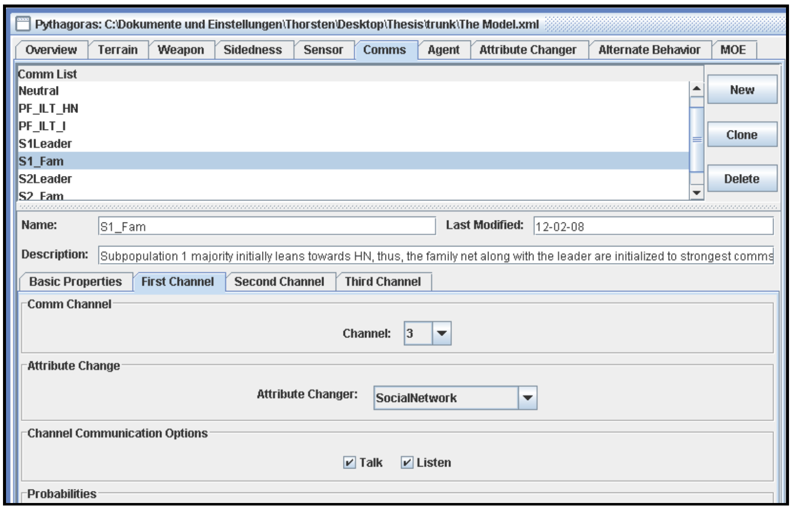

Figure 11. Communication Device Representing Social Influence

An agent can participate in several networks at once, but the networks he belongs to depend on his attitude towards the HN. So an agent can lose and gain network participations as his attitudes change, and thus his possibilities of influencing or being influenced by others can also change over time. This is explained in greater detail in Chapter IV.D.1, Social Network Implementation.

C. A MODEL OF INSURRECTION

1. Synopsis

The Model of Insurrection is based on a paper provided by Prof. McNab (2007) for the RUCG project (McNab, A Model of Insurrection, Annex C). It is summarized in this chapter (with slightly different notation) and forms the basis for the economic sectors representation in our model.

In his model, McNab sketches the sovereign's objective and its influence on the expected net income of families in a simple production economy.

The basic assumptions of the Model of Insurrection are:

- a simple production economy
- homogenous families
- the government collects taxes on labor
- the government employs soldiers to interdict any insurrection
- families allocate time to production, soldiering, or participation in an insurrection.

A family's expected income consists of three possible fractions:

- net income from production,
- net income from soldiering, and
- net income from insurrection.

Mathematically, this can be expressed as follows:

$$\mu_{NetIncome} = (1-t)\lambda l + (1-\beta) ws + \beta\left(\frac{ri}{I}\right)$$

where

- $\mu_{NetIncome}$ expected net income of a family

- t tax rate in %
- λ productivity of labor
- l fraction of time the family devotes to production
- β probability of a successful insurrection
- w wage rate for soldiers
- s fraction of time the family devotes to soldiering
- r total taxes per family
- i fraction of time the family devotes to the insurgency
- I fraction of time that families devote on average to participating in the insurgency

Due to the fact that a citizen cannot manipulate the variables that drive an economy, a family has to take t, λ, β, w, r, and I as given. The only way to influence the income is to choose the fractions of time spent in each of the three economic sectors. Hence a family can choose $l, s,$ and i such that

$$l + s + i = 1$$

We map this idea of a simple production economy by implementing economic sectors, regularly payments and taxes.

2. Pythagoras Implementation

In our model, three different terrains represent the three different production areas, derived from Prof. McNab's Model of Insurrections.

The three areas have the same dimensions on the playground, there is no difference in height or width. A portion of the playground is shown in Figure 12. Here the GUI-screenshot is misleading, the different area sizes in Figure 12 are due to technical reasons in taking the screenshot. The randomly distributed blue dots which can be seen in the areas are agents representing the populace that can move during the simulation, and red dots in the "straight line" of agents in the middle are stationary agents that are implemented to ensure proper movement of the population-agents.

The areas are called the Production_Force_EconomicSector (green), the Insurgency_EconomicSector (red), and the Soldiering_EconomicSector (blue). These names indicate the attitudes of the subpopulations "living" there (Figure 12).

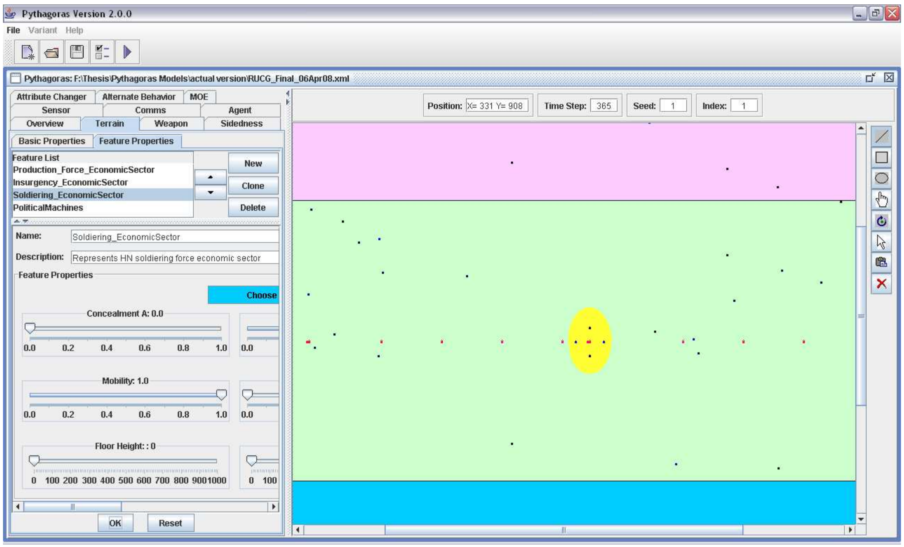

Figure 12. Economic Sectors

The yellow section in the middle of the playground is highlighted only to mark the location stationary agents with indirect weapons are operating from. This area possesses the same properties as the Production Force Sector.

According to McNab's Model of Insurrection, there is a tax rate associated with each area. So a subpopulation suffers a certain amount of negative income each time step it lives in the particular area. This tax rate is tied to an attribute changer and changes only the "EconomicSecurity" attribute, which stands for family income in the model. The Insurgency_EconomicSector possesses no taxes because it is assumed that members of the insurgency do not participate in the economy or pay taxes.

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IV. METHODOLOGY

In a stabilization operation, which normally takes place after a hot war or at least serious fighting, the most important objective for the local government and the stabilization forces is naturally achieving a positive attitude towards the HN within the population. It is easier to preserve law and order if people agree with the measures of their government, than with a dissatisfied populace. Thus, it is important for stabilization forces and politicians to know what kinds of actions will have the most positive effects on the population. With this knowledge, deliberate measures can be taken to influence the population and resources can be used effectively. Chapter VI describes the model methodology and discusses different approaches made to map the underlying analytical models in Pythagoras. Dead ends, errors, solutions, and ideas to represent human behavior in a stabilization operation are described, along with recommendations to improve the capabilities of the Pythagoras 2.0.0 software.

A. ATTITUDE TOWARDS HOST NATION

Color is the feature in Pythagoras that expresses the agent's affiliation. Red, green, and blue (RGB) are the three colors implemented; each color can take a value from 0 to 255, and a three-way-combination is valid. So an agent may have 15 red, 152 green and 250 blue, and his color on the monitor will be the corresponding mix. After experimenting with three-color-combinations we decided to represent an agent's attitude towards the HN in only one color. We chose blue because in military terms blue forces are “the good guys,” and stabilization forces acting in behalf of the United Nations or Western Democracies are supposed to be good. A multi-color representation for different subpopulations and actors is not practical due to the tedious unit – friend – neutral – enemy – calculations [PM, Agent Pairwise Color-Comparison Tool, 9.13]. We experienced that even for a one-color-representation and with the aid of the Excel-spreadsheet “Working Agent Pairwise Color Comparison” provided by NG as part of the Pythagoras software, the calculations quickly became very confusing.

A subpopulation that strongly agrees with the government's measures has a high blue value, while a subpopulation that has strong sympathies for the insurgency has a low blue value. This is the scale for the attitude towards the HN, the MOE of the study. A blue value of zero (0) represents an insurgent, 255 blue stands for a supporter of the HN. The agent's blueness represents his visible behavior, and it is the objective of a stabilization operation to influence the populace positively. The attitudinal model describes the way an agent is being influenced, and therefore the first approach to change the blueness of an agent is naturally to create paintball weapons [PM, Weapon Paintball Effect, 8.11] that add or subtract a certain amount of blue in each time step to an agent within range. Actions perceived as good add blue to the current value; actions perceived as bad consequently subtract blue. The challenge is to build an actor with a corresponding weapon for every action and to define the fire rate, the amount of blue transferred, Pk-probabilities, and other variables. In an early stage the model consists of exactly these different agents with paintball weapons to add and subtract blueness. It turns out that the attitude towards the HN can be represented with such an implementation and the attitudinal model is relatively easy to map in Pythagoras, as long as only the external influences are considered. As soon as the last part of the equation comes into play and the interactions between subpopulations participate in the value of blueness, this approach is no longer practical.

In order for two or more agents or subpopulations to influence each other they have to be connected in a social network. In real life people are influenced by their family, at school, at work, in sport clubs, etc. The ideas, thoughts and beliefs transfer through the networks and each participant is under this influence. In the long run, the influence transferred can completely change a person’s attitude. Someone who preferred playing tennis yesterday may prefer golf today, just because his friends now play golf. If the attitude towards sports was the MOE, the associated color of this agent would have changed.

To communicate this change in his attitude, the agent needs to talk to others. By passing the information to other agents, he can influence them and ‘pull’ them towards his opinion. That could be done by a machinery that compares the blue values of two agents and finds a new value that is a combination of these. Unfortunately, Pythagoras 2.0.0 possesses no such feature for colors. Information on the actual sidedness is transferred via the communication channels, so an agent knows about the color of others, but there is no means to influence (change the color) of another agent via the communication devices. This is the reason that this initial approach ended in a dead end.

To sum it up, a change in attitude towards the HN as expressed in the attitudinal model of Jacobs et al. can be implemented in Pythagoras 2.0.0 as long as the social network portion is not taken into account.

Because this is well known, Northrop Grumman developed Pythagoras 2.0.0 and implemented some features that should overcome these limitations. In Pythagoras 2.0.0 version 0 ten attributes are implemented, along with attribute changers that can alter attribute values of agents via communications devices, weapons, or terrain. Each different attribute can stand for a specific core belief of an agent, let's say for his religious opinions, his political view, his needs for financial or social security, and so forth. The sum of this beliefs result in the attitude of an agent. As mentioned before, the attitudes is expressed in blueness. So beliefs (attribute) sum up to attitude (blueness). Changing the value of attributes should therefore result in a change of attitude. This concept sounds reasonable and is indeed the concept of the model in order to map human behavior in the simulation software.

B. WEIGHTED ATTRIBUTES

Pythagoras provides no method to link attributes to color, so we developed a solution for this problem. First, the inner dependence of the attributes has to be examined more closely. A person normally does not consider all of his beliefs equally likely. He considers some more important than others, and if an opinion with a high priority and weight changes, the entire attitude of this person might change. Conversely, if one or more opinions that are considered less important change over time, the attitude per se will not change. An example of this could be religious conviction; a person who is a strong believer will change his attitude towards the HN after the HN rebuilds a mosque or a church because this is extremely important to him. Better infrastructure or physical security may not be as important to him, thus even when the HN builds streets and hospitals or ensures a safe environment it may not change his attitude towards the HN—he just doesn't care.

This theory means that the weight the of attributes is not the same in an agent, and therefore we introduced the idea of weighted attribute change. The maximum value of 1000 units of attributes equals 255 units of color. Therefore a belief that reaches the maximum value of 1000 will change the color to the maximum value of 255, and each unit of attribute equals 0.255 units of color. To demonstrate this idea, consider a single attribute called attribute 1. Because attribute 1 is the only one the agent possesses, it is weighted 100% and each change in attribute units is worth 0.255 units in color change. Therefore a change of 50 units in attribute 1 would result in $50 \times 0.255 = 12.75$ units color change. This is a theoretical value. Pythagoras 2.0.0 can only calculate integers as attribute values and so the change is actually 13. Now suppose an agent possesses four attributes, say 'Religious freedom,' 'Infrastructure,' 'Physical Security,' and 'Economic Security,' that all contribute to his overall attitude. A possible weighting for all four could be 25% each, that would mean the person believes each attribute is equally important. That kind of distribution is rarely true for people, and thus realistic models should allow each attribute to have a specific weight. Only four attributes are implemented in this model to demonstrate the general idea and show how it can be implemented in Pythagoras 2.0.0, but this can easily be extended to all ten possible attributes.

As an example of the methodology for color changes by changing weighted attributes, set the attribute trigger range to 50 units and the weights for 'Religion,' 'Infrastructure,' 'Security,' and 'EconomicS' to 0.5, 0.15, 0.05, and 0.3, respectively. As expected, these weights add up to 1.0. A proper color change amount after exceeding the threshold would be 12.75 color units, so the actual value is 13, as discussed earlier. Each attribute contributes to the color change accordingly to its weight, that is color change / weight, and therefore 'Religion' would contribute 6.5 units, 'Infrastructure' 1.95 units, ‘Security’ 0.65 units, and ‘EconomicS’ 3.9 units. Again, Pythagoras 2.0.0 uses integers for attributes, so the modeler must determine the actual values used. An example is given in Table 1.

Spreadsheet for Calculating Weighted Attribute Change

1000 Attribute units = 255 Color units.

Weights	0.5	0.15	0.05	0.3	Actual Color Change Implemented	Proper Color Change Amount	Color Change Implementation Errors (%) per Trigger Set
Example Issue Names	Religious Freedom	Infrastructure	Physical Security	Economic Security			
Attribute Trigger Set Ranges	Color Change for Attribute 1	Color Change for Attribute 2	Color Change for Attribute 3	Color Change for Attribute 4			
	Priorities						
	1	3	4	2			
10	1	0	0	1	2	2.55	21.57
20	3	1	0	2	6	5.10	17.65
30	4	1	0	2	7	7.65	8.50
40	5	2	1	3	11	10.20	7.84
50	6	2	1	4	13	12.75	1.96
60	8	2	1	5	16	15.30	4.58
70	9	3	1	5	18	17.85	0.84
80	10	3	1	6	20	20.40	1.96
90	11	3	1	7	22	22.95	4.14
100	13	4	1	8	26	25.50	1.96

Table 1. Spreadsheet For Calculating Weighted Attribute Change

In the highlighted case, the values are set to 6, 2, 1, and 4 to ensure that all attributes are considered. A value of 7 for ‘Religion’ and 0 for ‘Security’ would also be possible, but then the weak opinion of Security would be unconsidered at all. It can be seen in the last column of the table that there is a permanent error implemented in the attribute to color conversion due to rounding. Due to the relationship between the amounts of color change and attribute trigger set ranges, the modeler can reduce this error by choosing an appropriate range for his model.

C. ATTRIBUTE TO COLOR CHANGE

All subpopulations are constantly under the influence of various types of actions conducted by actors from the Host Nation and the Insurgency in the model. Each influence possesses attribute changers and all attributes of the agents are permanently changed, as discussed in Chapter II.D. A minimum and maximum threshold value is assigned to each attribute, and when the attribute value exceeds this threshold, the respective trigger trips and the agent starts to act as defined in an alternate behavior. This is discussed in Chapter II.G. Figure 13 shows an example for maximum and minimum threshold values and the color change event that is activated when the threshold is met.

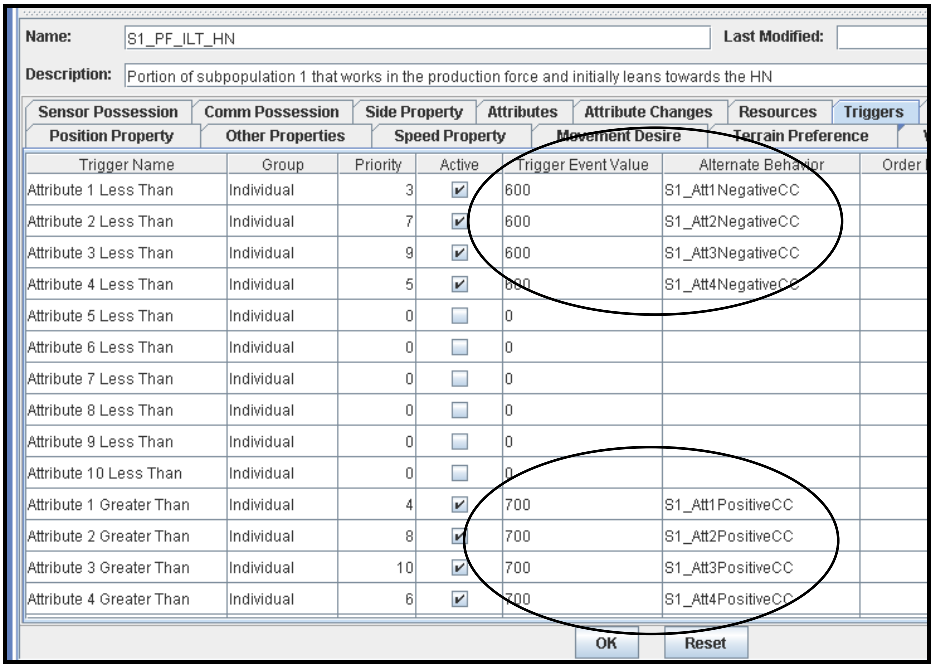

Figure 13. Attribute Thresholds

Exceeding the upper threshold activates an 'PositiveCC' event that leads to a positive color change, i.e., a color value is added to the current agent's color. After the 'PositiveCC' an agent, or a subpopulation, views the HN a little more favorably. An alternate behavior can redefine all the settings of an agent, but in this case we use the behavior only to give the agent a 'color splash.' When an agent acts in the 'Color Change (CC)' behavior, he gets a color change according to the weight of the attribute which reaches its threshold. This is realized in the Side Property environment because a color change is associated with sidedness. Figure 14 shows that the Delta Blue is added when the agent feels that 'All is Well' which is the situation when all other Side Changes triggers are not met [PM, Side change properties, 14.14].

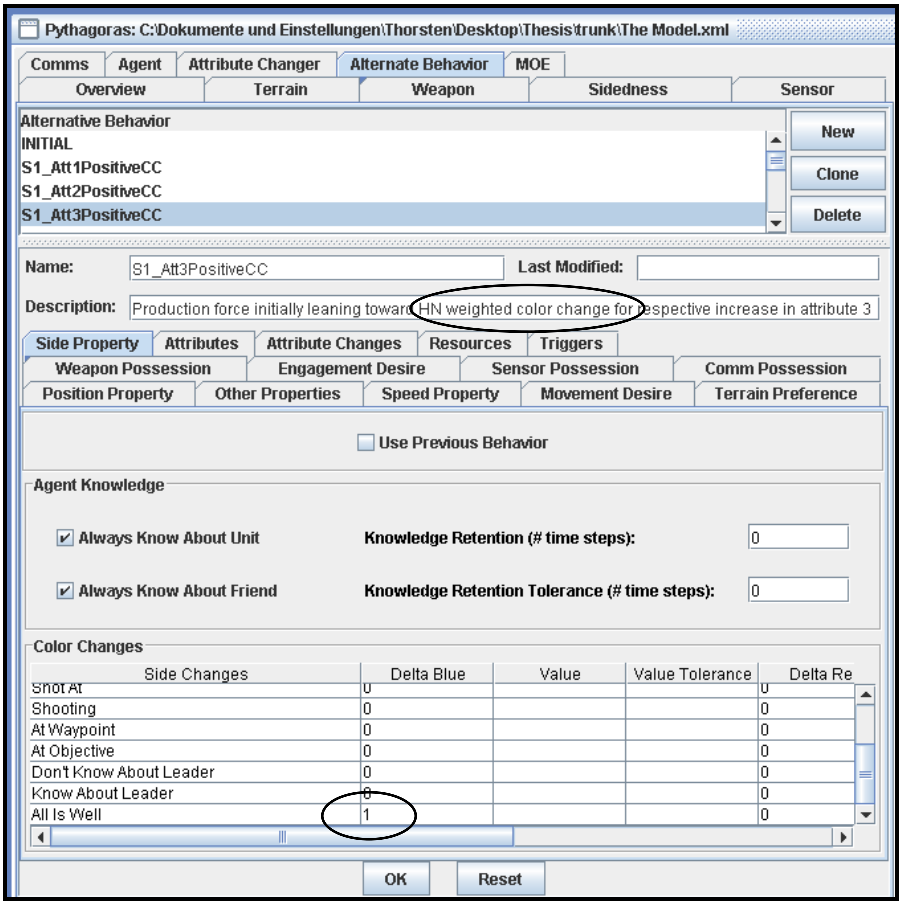

Figure 14. Alternate Behavior Color Change

In the current version of Pythagoras 2.0.0, using the fields on the Side Property Tab, Delta Blue is added in each time step. Recall that an agent stays in alternate behavior until a trigger event occurs and forces him in the next alternate behavior. As long as the agent stays in the color changing behavior, blue is accumulating. After 5 time steps the blueness has increased by 5 color units. This is not the desired way the color change should take place, because the change in attribute in this example is only valid for one unit of blue. Therefore, after activating the 'CC', the proper change should only take place for one single time step and after this the agent should leave the color-changing behavior and return to his initial behavior. This setup prevents the construction of exponential trigger trees as described in the following Chapter IV.C.1.

In the same time step, the attribute that causes the color change is reset to the mean value for the trigger setting; all other attributes keep their value. This resetting is necessary to prevent the attribute from initializing a trigger event in the next time step. Without the reset the attribute would keep its value and would trip, activating the next color change event for one time step, leaving the behavior in the next time step, triggering again and so forth. This would end in an endless trigger chain. Figure 15 shows the reset for attribute 3, the 'Reset?' button for the other attributes is not activated and these attributes stay unaffected.

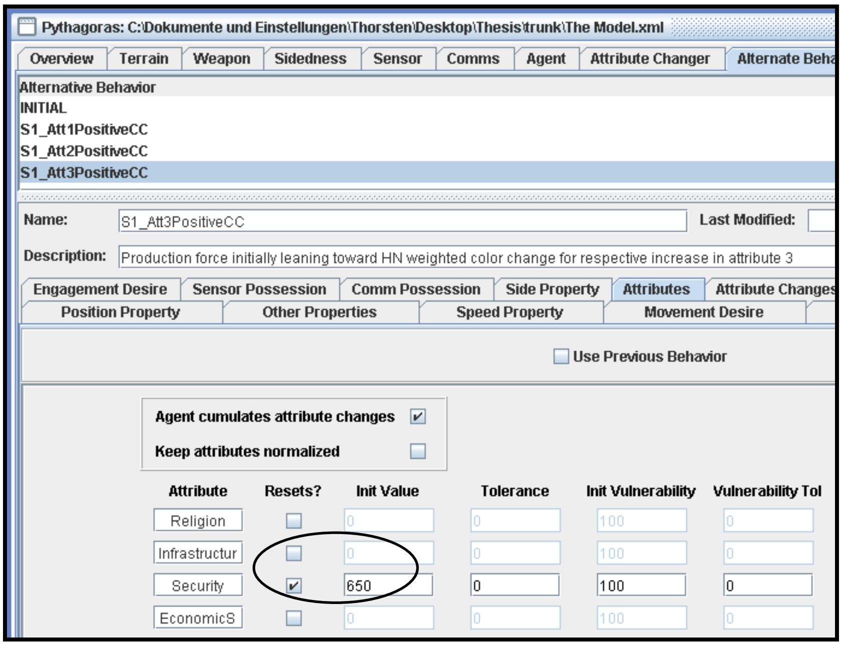

Figure 15. Attribute Reset

In this example the value is set to 650, which is midway between 600 and 700, the upper and lower thresholds of the attribute. Note that now the range for attributes to the next trigger event is ± 50. This is congruent with the attribute trigger set range discussed in Table 1.

This methodology describes the way the link between attributes and color is realized in the model. Beliefs, attributes, are linked to attitude, blueness. The attitude towards the HN, expressed in terms of the color value, is what drives an agent to participate in different social networks. Thus blueness determines an agent's membership in a social network.

1. Trigger Trees

As previously discussed, a trigger activates an alternate behavior and the agent stays in this until the next trigger trips. It is the nature of a stochastic simulation that it is not possible to predict with certainty which trigger will be the next to reach its threshold. Therefore the modeler has to create an alternate behavior for each possible situation. We now give an example for an agent with three attributes to explain why, in our model, attribute values are reset to a mean value as discussed.

The agent has three different attributes at simulation start. There are six possible ways to activate a trigger: Attribute 1, attribute 2, or attribute 3 can reach its respective upper or lower threshold. So six different alternate behaviors and actions have to be modeled. For the next step, there are 36 possible combinations to consider, because each attribute can once again trigger in two directions.

For the third step, $6^3 = 216$ possible combinations are necessary. This is graphically illustrated in Figure (16).

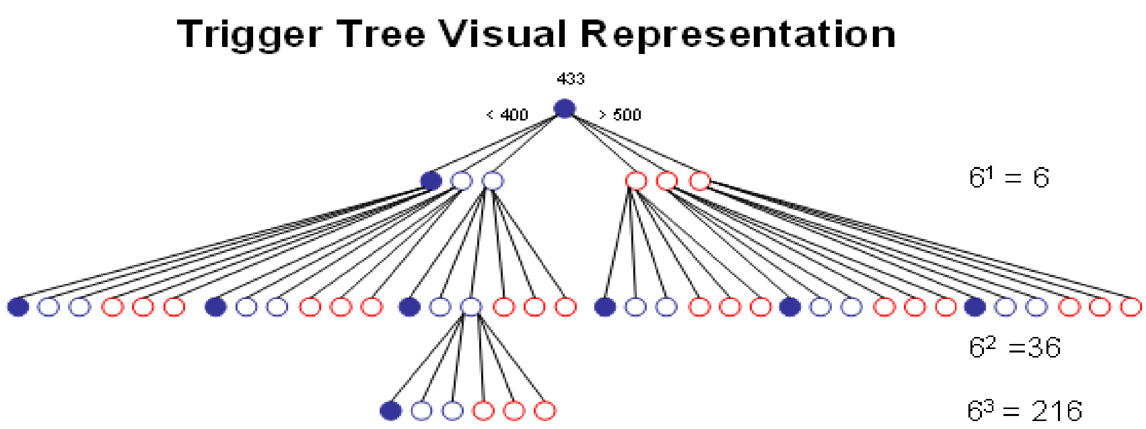

Figure 16. Visual Representation of a Trigger Tree

This "trigger tree" results from the fact that any of the three attributes can trigger but the values of the two other two attributes are "remembered" by the agent when this occurs. This is necessary because the change in an attribute represents the change of a specific attitude. So if influences cause the attribute that represents religious feelings to trigger and therefore change the color status of an agent, this agent will not forget his stand on political issues, infrastructural thoughts, etc. So one trigger results in three different possible ways to go.

The exact number of possible combinations is not easy to determine because the span of the trigger tree depends on the initial values of the attributes. If an agent starts with a high blue value, this also means a high attribute value due to the described relation between blueness and attributes and there is only one direction a trigger set can be activated. An attribute that is nearly maxed out (e.g., with a value of 995) cannot trigger in an alternate behavior which would possess a value greater than 1000. So the attribute can only trigger if the value drops below the lower threshold, and so this trigger tree starts only with half of the possible directions. If the attribute values decrease, there is of course the whole set of possible directions, and so the expression "half of the possible directions" is only valid for the extreme high and low attribute values. Whenever an attribute value reaches the end stage, there is only one way to go: an attribute reaching 0 will go up, and an attribute reaching 1000 will go down.

The number of necessary trigger options (T) actually depends on the number of levels the agent can pass until he reaches the end states HN or I. The number of levels is calculated by dividing the maximum attribute value of 1000 by the chosen trigger set width. Table 2 shows some examples.

Trigger Set Width	Levels
50	20
100	10
200	5
250	4
500	2

Table 2. Possible Number Of Levels Depends On The Trigger Set Width

The value (T) can than be approximated as

$$T \approx \sum_{i=1}^{Levels-1} (2A)^i + \frac{1}{2}\left[(2A)^{Levels}\right]$$

where

- T = # trigger options,
- A = attributes used,
- *Levels* ~ (Trigger set width(W)), and
- $i = 1, \ldots., (level - 1)$.

W is the trigger set width and represents the desired fidelity of the model. Table 2 shows maximum and minimum numbers of triggers for different number of attributes and two optional trigger set ranges. Note that a range of 250 units in attributes means that an influence has to alter the belief of an agent by 25% to activate a color change. That clearly is a tremendous decrease in model fidelity.

Attribute Range: 0 to 1000			Desired Trigger Set Width (Represents Fidelity)	
			100	250
# of Levels			10	4
# Attributes	2	Min	2046	30
		Max	1398100	340
	4	Min	1398100	340
		Max	1227133512	4680
	6	Min	72559410	1554
		Max	67546215516	22620
	8	Min	1227133512	4680
		Max	1.17281E+12	69904
	10	Min	11111111110	11110
		Max	1.07789E+13	168420

Table 3. Approximate Bounds On The Number Of Trigger Options

The values in Table 3 are approximate values because they do not take into account the fact that only half of the trigger directions are possible on the last level as described earlier. The numbers in Table 3 represent the maximum and minimum number of levels an agent can trigger through according to

$$\min \approx \sum_{i=1}^{Levels} (A)^i \leq T \leq \sum_{i=1}^{Levels} (2A)^i \approx \max .$$

The minimum number of trigger options is the number that occurs if a single attribute always determines the trigger in a single direction (up or down) and the other attributes are not considered. This best-case scenario is unrealistic, but even so the number of possible trigger options (and consequently the number of needed alternate behaviors) grows exponentially. In a realistic timeframe it is not possible to build these options, therefore we used the solution discussed in Chapter IV.C. and send the agent back to the only behavior that is really known: the initial behavior.

D. SOCIAL NETWORKS IMPLEMENTATION

A society consists of a great number of social classes. Members of these classes share the same ideas, thoughts and beliefs and are connected with an a social network. The reasons for belonging to a social network can be very different. They can depend on birth, education, profession, religion, hobbies, politics, and a lot more. Being part of a social network means spending time together, talking to each other, sharing information and, at the bottom line, influencing each other. A social network is never homogeneous, i.e., social networks do not consist of only one typical type of member. There are always different types of members with different connections to external networks. A tennis club, for example, consists not only of doctors; there are lawyers, teachers, manager, soldiers, housewives, truck drivers, etc., enrolled. They all have their own network connections outside the tennis club, and so ideas from other networks find their way in the club and, naturally, spread about via this channels and influence other parts of the society. So all networks are interconnected and the information exchange is fluid.

The membership in a specific social network depends on the personal situation and can vary over time. High school connections may weaken after graduation, when friends go to different colleges, or may get lost completely. But other networks kick in as this happens, and this process repeats itself over a person's entire life. There is only one network one never loses, despite what situation one lives in—the family network. The connection maybe weak and irregular, but a mother will always talk to the children. No matter what, 'blood is thicker than water.'

1. Social Network Setup

To represent the membership in a network, blueness is used in our model. Each member of a subpopulation has an initial blueness at simulation start. This value describes its initial attitude towards the HN and defines the networks it is participating in. The possible values for blueness are 0 to 255, therefore we defined color-bins to represent social networks. As shown in Figure 17, the color-bin assigned to the insurgency ranges from 0 to 25, the soldiering-bin from 230 to 255. There are 14 color-bins implemented in the model, representing the different combinations of social networks an agent can participate in. These combinations can be seen in Figure 18 on an imaginary vertical axis. An agent with blueness 110, e.g., possesses the “Network of civilians partial to insurgency, blueness between 25 and 127” (pink) and his “Subpopulation family network” (orange).

Each network has a Comm Type assigned, and effectiveness values can differ by Comm Type. An agent is part of all the networks that correspond to his blueness value, and possesses all the Comm Types associated with these networks.

We define several networks in the model with different ranges. Some of the networks are disjoint, but others overlap. The insurgency network ranges from 0 to 25, the network of civilians partial to insurgency from 25 to 127, the network of civilians partial to HN from 127 to 230, and the soldiering network from 230 to 255. A neutral network which connects the insurgency and the soldiering network ranges between 116 and 137, and two family networks, one for the subpopulation that initially leans towards the HN and one for the supporters of the insurgency, span the entire spectrum. This is graphically shown in Figure 17.

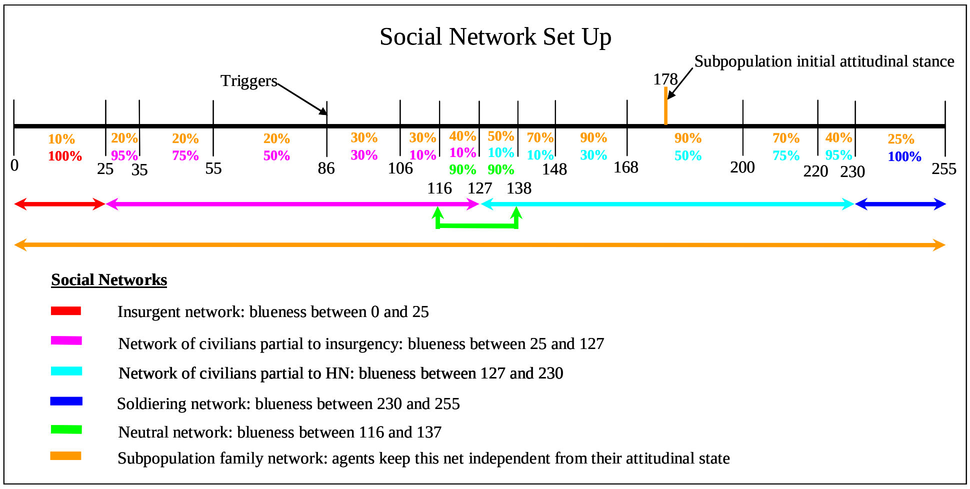

Figure 17. Social Network Setup

Depending on the color-bin, the effectiveness of the participation in a network varies. The part of the subpopulation with an initial attitudinal stance represented by 178 in blueness lives in the color-bin between 168 and 200 and therefore takes part in two networks: his family network and the network of civilians partial to HN. Because 178 is the initial blue value for this subpopulation, the effectiveness for the participation in the family network is set to the maximum possible value of 90%. Our modeling assumption is that even in a family, the communication is not perfect.

If a member of this subpopulation gradually changes his attitude towards the HN over time and becomes a supporter of the insurgency, he will proceed through different color-bins, and in each bin the agent possesses different Comm Types with different settings. Losing and gaining network participations is possible. He adds the neutral network component but does not give up his connection to those partial to the HN when his blueness is between 127 and 138. He keeps this neutral network component, stops talking to civilians partial to the HN, and starts talking to civilians partial to the insurgency when his blueness falls between 116 and 127. Later on his way to becoming a terrorist he will lose this neutral connection as well as obtain access to the insurgency network. An example of an agent that starts in his original family color-bin and changes his attitude towards the insurgency is given in Figure 18. This agent now acts in the alternate behavior S1_BluenessBetween35-55 and has switched to the insurgency network. Note that he still possesses his family network, but its effectiveness has dropped from 90% to 20%.

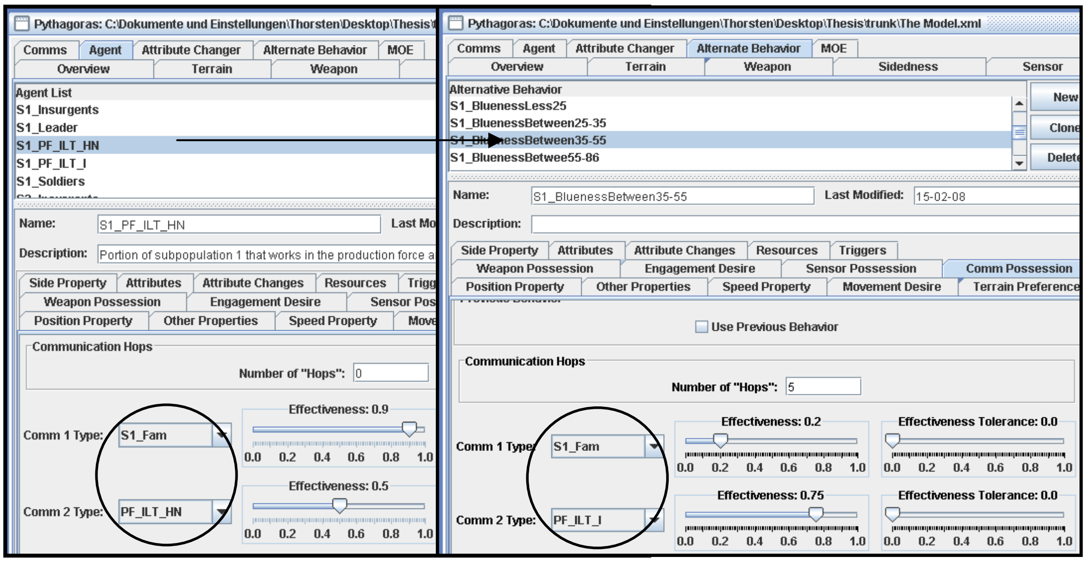

Figure 18. Change of Social Network Participation

Before an agent actually loses a network connection, it fades out. This fading is not a gradual process but happens with each "jump" in a new color-bin. In Figure 18 it can be seen that, e.g., the fading out for the insurgency net needs 7 adjacent color-bins from the very left position on the scale to the middle, where a switch over to the soldiering network takes place. That represents the real life situation that one talks less to his old friends before after a while the connection is terminated. Only the family connection never gets lost completely, there is always a band (weak maybe, but present) tied between family members.

The neutral network in the color range between 116 and 138 represents the idea of a continuous flow of information through a network. There is no clearly-defined cut when an agent more leans towards the HN or towards the insurgency. There is a neutral zone in which a subpopulation has not decided whether to support the HN or not. Thus these parts of a population talk to both sides, and information can flow through these agents from one side to the other. In terms of the model, this means that if a supporter of the HN influences a neutral agent and changes his attribute values, this neutral agent can, in turn, influence an insurgent and pull him towards the HN by changing his attributes. So the influence is passed and the HN has a link to the insurgency. That is true for the reverse direction as well.

In Figure 19 it can be seen that an agent who has altered his initial attitude towards HN acts in an alternate behavior. Triggers activate these alternate behaviors, and the upper and lower thresholds for the triggers in a behavior are the edges of the color bins. An agent with initial blueness of 178 will act in the appropriate behavior for the 200 to 220 bin after the blueness value exceeds or is equal to 200. The lower threshold value is always included in the color bin, the upper value is excluded, and so the trigger values are always equal to the upper limit and one less than the lower limit. That prevents an overlapping of the bins. If the bins overlap, the triggers will trip the agent back and forth whenever a threshold is met exactly. If 200 is met, the two instructions 'greater than or equal to 200' and 'less than or equal to 200' from the adjacent bins would bounce the agent between these two bins every time due to the priority of color triggers. As shown in Figures 17 and 19, the triggers correspond to the color bin edges.

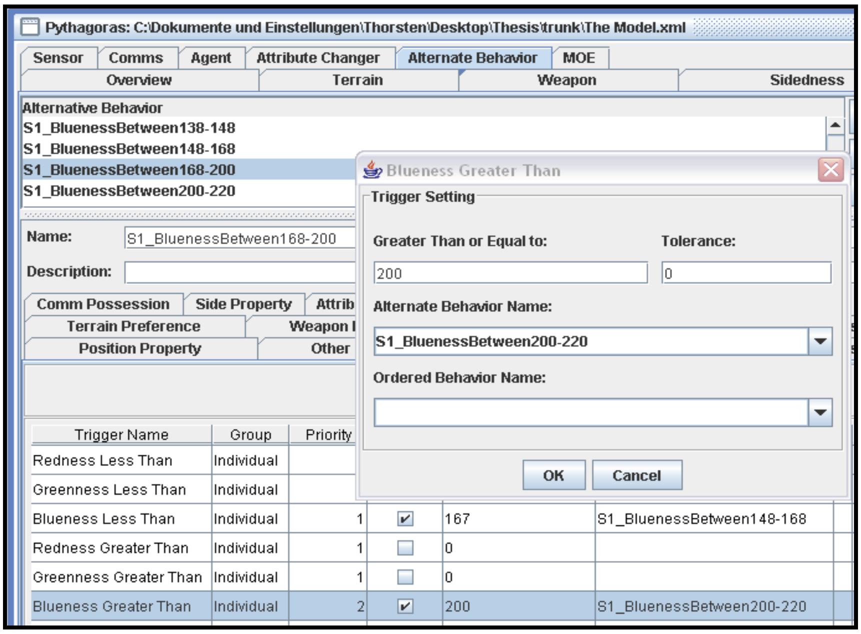

Figure 19. Trigger Setting for Social Networks

The model contains alternate behaviors corresponding to the proper color bin for both subpopulations. If a modeler wants to extend the number of subpopulations in the model, he must create alternate behaviors representing color bins for each additional subpopulation.

The attitudinal model by Jacobs et al. states “that there are *S* subpopulations (homogenous group of people)” in a population. The model of McNab describes the overall net income of a subpopulation as a function of the amounts of time the subpopulation takes part in insurrection, production, or soldiering activities. To combine these two models, we divide the 2 subpopulations acting in the model into smaller parts and spread these parts over the possible economic sectors in the model. So, for example, subpopulation 1 (S1) consists of

- **S1_Insurgents**,
- **S1_PF_ILT_HN**,
- **S1_PF_ILT_I**, and
- **S1_Soldiers**.

The **S1_Leader** is a special agent; his tasks will be discussed later. The separate parts of the subpopulation (e.g., **S1_Soldiers**) are homogenous and therefore meet the requirements of the attitudinal model.

The idea behind this is that not all members of a subpopulation have the same thoughts and beliefs. Not all visitors of a specific mosque are soldiers, plumbers, or terrorists. But certain percentages of them are similar, and so the subpopulation’s distribution reflects this. Because subpopulation S2 initially leans towards I, there are more instances of **S2_PF_ILT_I** (10) placed on the playground than instances of **S2_PF_ILT_HN** (4). This distribution is sketched in Figure 20.

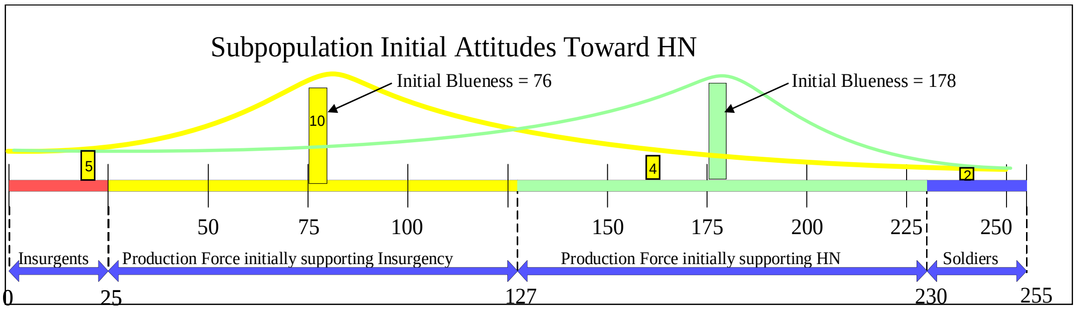

Figure 20. Distribution of Subpopulations

There is one special agent in each subpopulation called the Leader. This leader is implemented in the model with respect to the leading function of a clan leader in a tribal society. His influence and emphasized position are discussed in Chapter I.D. Because a clan leader has a higher influence than other members of a clan or subpopulation, the communication settings of a leader agent differ from the settings of a normal agent. First, he possesses a communications channel which is set to 'talk only,' and on this channel he passes influence to his subpopulation without being influenced in reverse. This one-way connection between a leader and the subpopulation is the main difference between these agents and implements the idea of a patriarchic society. Second, the value of the `SocialNetwork_Leader` attribute changer is set to a substantially higher value than the value of the mutual `SocialNetwork` attribute changer that every agent possesses, which represents the superior influence.

As discussed in Chapter IV.C, color is changed via altering attributes, therefore all Comm Types in the model possess an attribute changer called `SocialNetwork`. This changer is active on all four attributes in the model and changes the attribute values by relative 1% in every time step. "The agent's attribute value is changed to be closer to the attribute value of the agent that possesses the communication device that has the attribute changer" [PM, Attribute Changers, Relative, 13.5.2.2].

Pythagoras 2.0.0 considers every agent in each time step, and therefore on every communications connection the influence is passed through the network in both directions. If agent 1, for example, has a Religion value of $R = 200$ and agent 2 has a Religion value of $r = 30$, then two calculations will be done to determine the new attribute values at the end of the time step. First agent 1 possesses the communication device and influences agent 2 according to the formula $r_0 + (R - r_0) \times 0.01 = r_1$, then agent 2 influences agent 1. The attribute values for agent 2 at the end of the time step is $30 + (200 - 30) \times 0.01 = 31.7$. Agent 1 will have a value of $200 + (30 - 200) \times 0.01 = 198.3$. Pythagoras 2.0.0 rounds these values up to 32 and 199. In a network with many participating agents, Pythagoras 2.0.0 creates a list with all changes for each agent and accumulates these changes at the end of the time step. For greater accuracy, the rounding is done only once at the end of the time step. Figure 21 gives an idea of the complexity of the social network of the model where every blue line represents a network connection between agents. It shows that agents of different attitudes talk to each other on various networks.

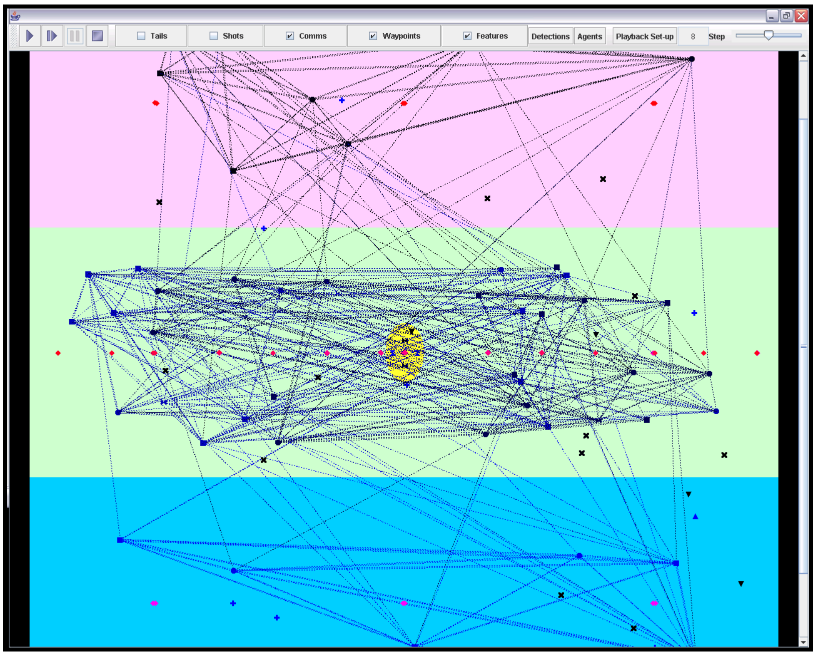

Figure 21. The Social Network in the Playground

2. Trigger Trains

Recall that after a color change event an agent is sent back to his initial behavior without resetting his blueness attribute value. This prevents the building of exponential trigger trees as discussed in Chapter IV.C.1. but leads to another problem, so-called ‘Trigger Trains.’ At each time step the trigger sets check to if all conditions for the actual behavior is met, and if not, a trigger trips and activates an alternate behavior. As discussed in Chapter II.G., the trigger with the highest priority kicks in and all other trigger settings are ignored in this particular time step. Color triggers are superior to attribute triggers, so an agent will begin by changing their behavior until it matches their color representation. It may take several time steps to trigger back to the proper behavior for the color representation. If an agent’s initial color value at simulation start is 178 and this value changes to 34, it takes 8 time steps to trigger him back in the 25 to 35 behavior bin after he restarts in his initial 168 to 200 behavior bin. An example from an actual simulation can be seen in Table 4.

A	F	K	L	
timestep	**Blue w/ triggers**	**Alternate Behaviors (w/ Blueness Triggers)**	**Triggers**	
34	134	INITIAL	Relative Time Step	
35	134	S2_BluenessBetween86-106	Blueness Greater Than	
36	134	S2_BluenessBetween106-116	Blueness Greater Than	4
37	134	S2_BluenessBetween116-127	Blueness Greater Than	
38	134	S2_BluenessBetween127-138	Blueness Greater Than	
39	143	S2_Att1PositiveCC	Attribute 1 Greater Than	
40	143	INITIAL	Relative Time Step	
41	143	S2_BluenessBetween86-106	Blueness Greater Than	
42	143	S2_BluenessBetween106-116	Blueness Greater Than	5
43	143	S2_BluenessBetween116-127	Blueness Greater Than	
44	143	S2_BluenessBetween127-138	Blueness Greater Than	
45	143	S2_BluenessBetween138-148	Blueness Greater Than	
46	152	S2_Att1PositiveCC	Attribute 1 Greater Than	
47	152	INITIAL	Relative Time Step	
48	152	S2_BluenessBetween86-106	Blueness Greater Than	
49	152	S2_BluenessBetween106-116	Blueness Greater Than	
50	152	S2_BluenessBetween116-127	Blueness Greater Than	6
51	152	S2_BluenessBetween127-138	Blueness Greater Than	
52	152	S2_BluenessBetween138-148	Blueness Greater Than	
53	152	S2_BluenessBetween148-168	Blueness Greater Than	
54	161	S2_Att1PositiveCC	Attribute 1 Greater Than	
55	161	INITIAL	Relative Time Step	
56	161	S2_BluenessBetween86-106	Blueness Greater Than	
57	161	S2_BluenessBetween106-116	Blueness Greater Than	
58	161	S2_BluenessBetween116-127	Blueness Greater Than	6
59	161	S2_BluenessBetween127-138	Blueness Greater Than	
60	161	S2_BluenessBetween138-148	Blueness Greater Than	
61	161	S2_BluenessBetween148-168	Blueness Greater Than	
62	170	S2_Att1PositiveCC	Attribute 1 Greater Than	
63	170	INITIAL	Relative Time Step	

Table 4. Visualization Of A Trigger Train

Column K shows that the trigger train grows the further away an agent’s attitude from his initial stance is and the longer it takes for an attribute trigger to kick in and activate a color change event. Note that between time step 53 and 61 the color value increases from 152 to 161, but because these values are located in the same color range, the trigger train gets no longer. The delay for proper behavior for a color change to kick in has a negative impact on the proper color representation; we found out during the simulation runs that the mean error can sum up to nearly 35% to the accurate color values (Figure 22).

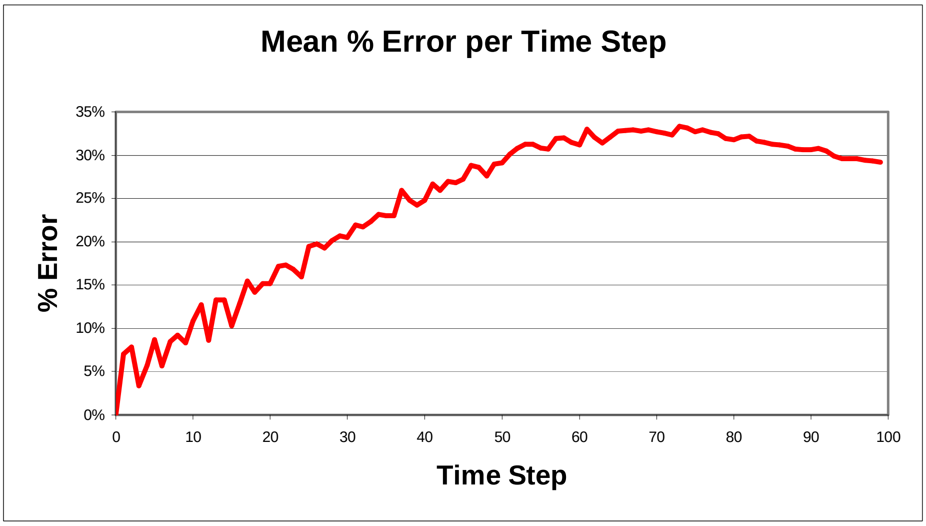

Figure 22. Mean % Error in Blueness Resulting From Trigger Trains

This phenomenon and the error analysis is discussed more deeply and in detail in the thesis of Major Todd Ferris, USMC.

3. Priority Lag

The prioritization of trigger events results in another form of undesirable performance. For a specific trigger event to activate an alternate behavior, the assigned attribute value must simultaneously exceed a threshold value and the trigger must be the one with the highest priority of all triggers that could trip in the time step. Only one trigger among the set of possible triggers is considered in each time step; the others have to wait until later time steps when they meet all requirements to trip. This causes a time delay for all triggers that exceed their associated threshold values but have a low priority. Consequently this results in an inaccuracy of color representation, because an attribute that is ready to activate a color change event has to wait until all higher priority attribute or color triggers are complete. We called this a ‘Priority Lag.’ Table 5 shows the impact of priority lags and the influence on a proper color representation.

timestep	Attribute1	Attribute2	Attribute3	Attribute4	Blue w/ triggers	Accurate Blue Representation	Difference	Alternate Behaviors (w/ Blueness Triggers)
0	307	307	307	307	76	76	0	<INITIAL>
1	259	316	316	316	85	90	5	S2_Att1PositiveCC
2	268	325	325	325	85	90	5	INITIAL
3		334	334	259	88	90	2	S2_Att4PositiveCC
4		343	343	268	88	90	2	INITIAL
5	295	352	352	277	88	90	2	S2_BluenessBetween86-106
6	304	259	361	286	89	90	1	S2_Att2PositiveCC
7	313	268	370	295	89	104	15	INITIAL
8	322	277	379	304	89	104	15	S2_BluenessBetween86-106
9	259	286	388	313	98	104	6	S2_Att1PositiveCC
10	268	295	397	322	98	104	6	INITIAL
11	277	304	406	331	98	104	6	S2_BluenessBetween86-106
12	286	313	415	259	101	104	3	S2_Att4PositiveCC
13	295	322	424	268	101	118	17	INITIAL
14	304	331	433	277	101	118	17	S2_BluenessBetween86-106
15	259	340	442	286	110	118	8	S2_Att1PositiveCC
16	268	349	451	295	110	118	8	INITIAL
17	277	358	460	304	110	118	8	S2_BluenessBetween86-106
18	286	367	469	313	110	118	8	S2_BluenessBetween106-116
19	295	376	478	259	113	132	19	S2_Att4PositiveCC
20	304	385	487	268	113	132	19	INITIAL
21	313	394	496	277	113	132	19	S2_BluenessBetween86-106
22	322	403	505	286	113	132	19	S2_BluenessBetween106-116
23	259	412	514	295	122	132	10	S2_Att1PositiveCC
24	268	421	523	304	122	132	10	INITIAL
25	277	430	532	313	122	146	24	S2_BluenessBetween86-106
26	286	439	541	322	122	146	24	S2_BluenessBetween106-116
27	295	448	550	331	122	146	24	S2_BluenessBetween116-127

Priority Lag

Table 5. Influence Of Priority Lag

In this example the lower and upper thresholds for all attributes are set to 200 and 300, and the reset values equal 250. Attribute 1 has the highest priority, the second highest priority is assigned to attribute 4, attribute 2 has the third highest priority and attribute 3 the lowest. Table 4 shows that all four attributes exceed the upper limit at simulation start, but only attribute 1 trips because it has the highest attribute priority. So the color event for attribute 1 is activated, S2_Att1PositiveCC. After one time step, the agent goes back to his initial behavior. In the next time step attribute 4 (second highest priority, now the one with the highest not tripped) meets all requirements to trip, attribute 2 and 3 must wait. Note that in time step 5 a color trigger kicks in. Color triggers have always the highest priority and activate their alternate behavior first. When an attribute trigger is activated, the attribute value is reset to the mean value of the thresholds, here

250. Because the influence in each time step equals nine units in attribute, this is added immediately per time step and therefore the number seen is 259.

Table 5 shows that the lower priority triggers are tripped less often because the higher priority triggers dominate. In fact, attribute 3 *never* trips in this example and so it *never* contributes to the color representation. In the column ‘Accurate Blue Representation’ the value is listed that a properly running simulation would produce; in ‘Difference’ the error per time step is calculated. This error increases the longer the simulation runs and reaches a value of approximately 35% as stated in Chapter IV.D.1. Again, for a more detailed analysis of these types of errors we refer the reader to Major Todd Ferris’ thesis work [Ferris 2008].

Because priority lags have a significant impact on the proper color representation we recommended a software change. A possible solution for this problem could be to loosen the priority restrictions in Pythagoras and allow it to assign equal priorities to numerous triggers. Besides this, a trigger event should be capable of using an attribute changer the same way that communications devices and weapons can use an attribute changer. Than an active trigger could change an attribute value via an attribute changer, and more than one trigger could be active in a single time step. It is mandatory that an attribute changer is activated and not an alternate behavior, because Pythagoras remains a combat model and an agent can only be in one behavior at a time. Allowing an agent to be in more than one behavior simultaneously would completely change the underlying logic of the program and is unrealistic.

Northrop Grumman reviewed these recommendations and has them on the list for future code changes.

E. ECONOMIC INSURRECTION MODEL

The economic segment of the model is based on the model of Prof. McNab and the theory that the net income of a family (subpopulation, or agent) consists of the incomes from productive activities, soldiering or insurgency, and insurgency activities (Chapter III.C.). Therefore we implemented the concept that a family can choose the source of its income and that this is dependent on the family’s attitude.

1. Income

Pythagoras contains three generic resources x, y, and z [PM, Resources, 12.26]. These resources could represent economic security, say money or income. A possible way to use one of the resources to implement an economic model in the simulation is to assign 'family income' to a resource. The resource tab allows to define a total amount of the resource and a consumption rate (Figure 23).

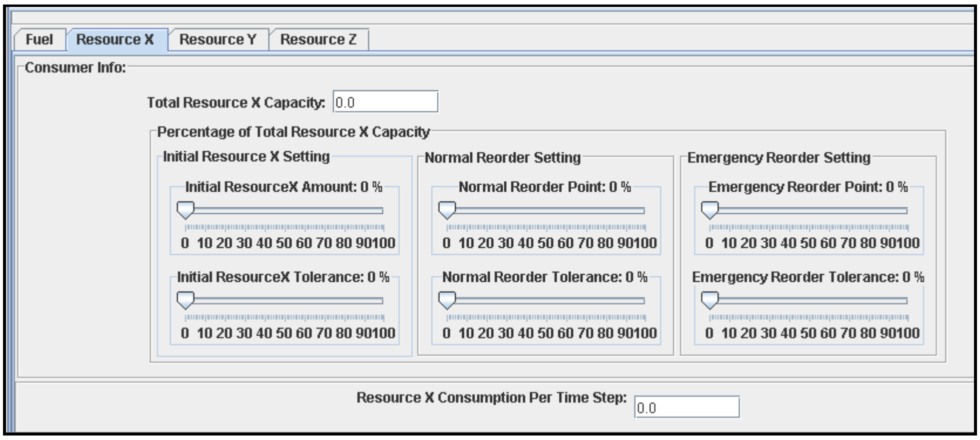

Figure 23. Income Representation Based on Resources

In terms of an economic model, resource x could stand for money. The agent's supply of resource x increases when he gets a paycheck, but he must spend a certain amount of money each day to support his family. When he runs out of the resource he can go to a re-supplier and get new resources. In our generic scenario, a family father who is employed can get his payment from his boss or from whoever is willing to provide it. If the company where the agent is employed can no longer provide economic security, he has to go to another supplier because his priority is to support his family. The supplier settings are definable on the resource tab, as shown in Figure 24.

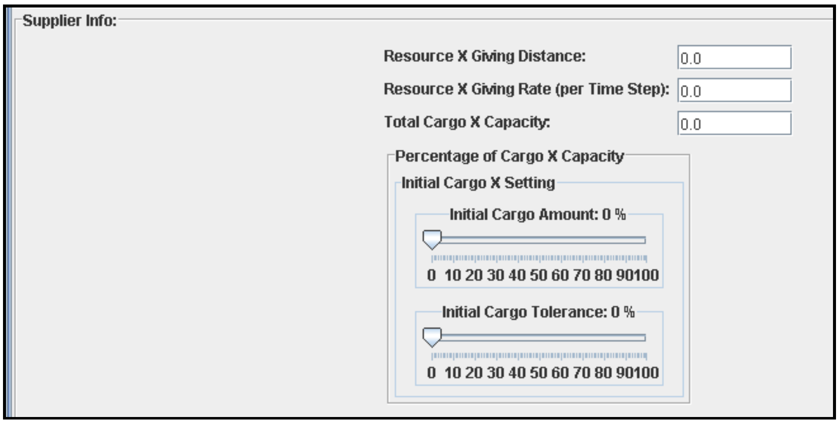

Figure 24. Supplier Settings

As a combat model, the supply options of Pythagoras are restricted to disallow resources to be transferred between agents unless they are not enemies. That means if the supplier sees the customer as an enemy, he will not supply. If the customer sees the supplier as an enemy, he will not accept the supplies. Hence, a supporter of the HN can not go to an insurgency's provider of economic security and get paid there.

Because resources are not suitable for representing payments and an agent cannot take the money from all providers, we introduce a solution based on economic regions, weapons and attribute changers. A region of the playground is assigned to each part of the economy. Three sectors represent the entire economy: a soldiering, a production, and an insurgency sector. Economic security providers are located in each economic sector, and each of them possess one indirect weapon with an attribute changer to affect the subpopulation on the playground. In Figure 26 the circles represent the areas of payments, one supplier is located in the middle of each circles. There are three suppliers in each sector (only two are active in each sector in the provided screenshot), and the range of the circles covers nearly the entire economic sector. These payment areas of the providers do not overlap, so there are small proportions in the economic areas where an agent gets no payment. With this setting an overpayment is avoided, and it also implements the possibility of not getting a paycheck due to insolvency (Figure 25).

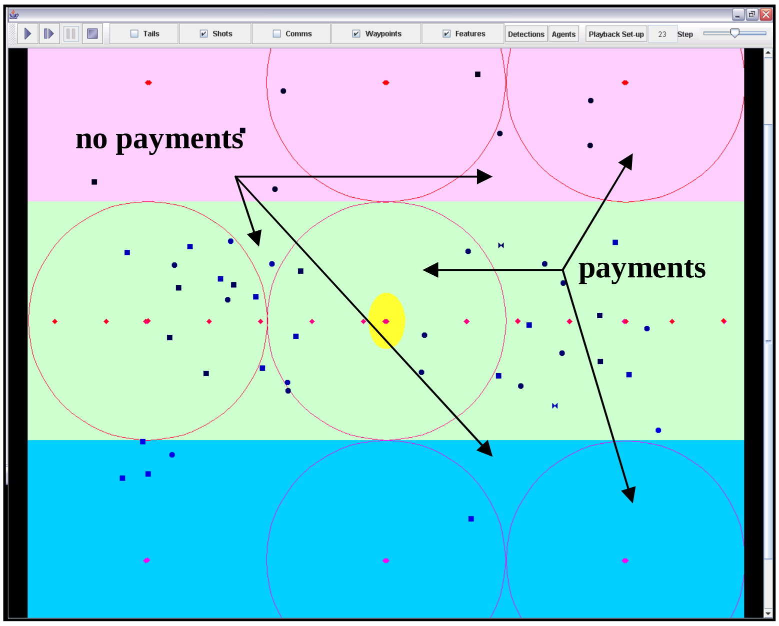

Figure 25. Payment Representation in Economic Sectors

As discussed in Chapter III.C., the individual net incomes are not only functions of sector wages, but also functions of sector tax rates and the times spent operating in the sectors. Sector tax rates are implemented by assigning an attribute changer to the production force economic sector and the soldiering economic sector. The insurgency economic sector has no taxes assigned due to the assumption that members of the insurgency do not pay taxes. The attribute changers possess a negative value only for the 'EconomicS' attribute and reduce the income every time step incrementally.

An agent has to stay in a sector only as long as he is willing to take his paycheck from the providers in that sector. When his attitude changes and he is not longer part of, say, the insurgency, he has to leave the insurgency sector and must move towards the production force economic sector.

2. Movement

To realize the movement of agents towards the proper economy security provider in the correct economic sector depending on their attitude, movement desires and specially designed movement-leader agents are built into the model. The only task for the movement-leader agents is to act as beacons for the agents to guide their movement; they should not be mixed up with subpopulation leaders. According to the naming convention they are named '…_for_MovementOnly…'; they are placed on the playground with respect to their individual tasks. To be accepted by the agents as a leader and to act as orientation point, the leadership value is set to 100%. With this setting, the movement-leader will always be seen as leader by an agent (Figure 26) [PM, Leadership Property, 12.11].

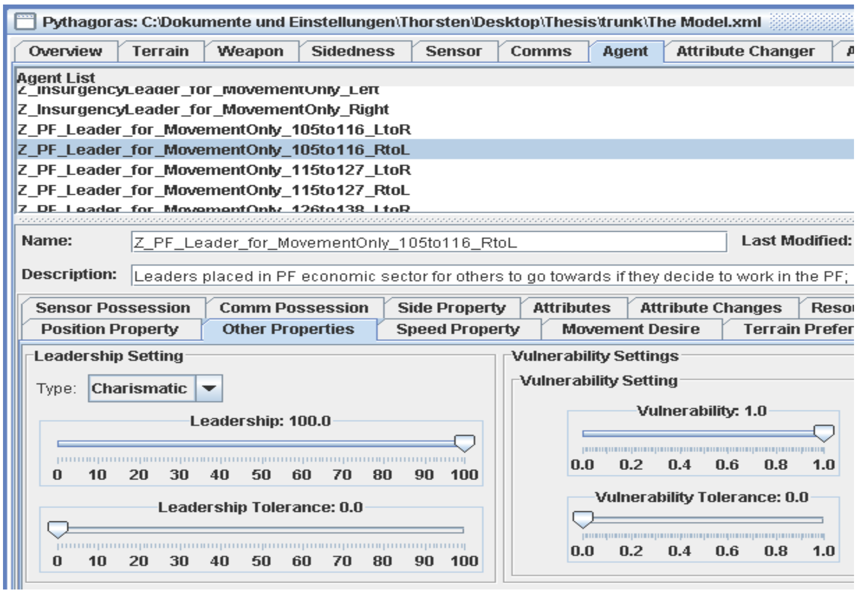

Figure 26. Movement Leaders

The movement desire of an agent is set in the corresponding tab of the agent's settings. Distance settings ensure that an agent always move towards his respective leader. To establish a leader-subordinate relationship, both agents must be members of the same unit, and so the sidedness of the movement-leaders correspond to the color bins introduced with the social networks. As an agent changes his attitude, he notices different movement-leaders as part of his unit, accepts them as leaders, and moves towards them. With this implementation the link between attitude and economic sectors is established.

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V. ANALYSIS

A. DESIGN OF EXPERIMENT

In the model development phase and the ongoing tests some unexpected results occurred. After completing the social network components and defining the influence parameters, small experiments revealed that all agents who initially leaned towards the insurgency became soldiers and all soldiers became insurgents. This is not the desired result. This behavior is driven by improperly working communications devices, which in the simulation represent social networks of the population. Therefore a detailed analysis of the ongoing procedures in the communication devices of Pythagoras 2.0.0 is conducted. The objective of this analysis is to provide an exact understanding of what causes the problems and how to fix them.

The idea behind the social network implementation in the model is to map the participation of agents in realistic social structure settings. Because a human can simultaneously be part of several different social structures, an agent can possess more than one communication device and, therefore, can participate in several networks. In each network an agent can influence and be influenced by other agents.

To identify errors and inaccuracies, the model is reduced to the simplest one possible: a single influencing agent who represents the leader of the particular subpopulation (L) and a member of the subpopulation which follows him (F) remain for the "error hunt." These agents still retain the complete methodology implemented in the model to ensure that no characteristics of the mapping get lost.

The rudimentary model is shown in Figure 27, a screenshot of the Pythagoras Graphic User Interface (GUI). The leader agent (circle) is located close to the influence (hour glass) and is the only agent that is influenced directly. The member of the subpopulation (diamond), is so far away from the influential weapon and that he is outside the range of influence. The only way to influence the follower is via the communications between L and F. In this scenario F has a "listen only" communications device and therefore can give no feedback to his leader. To ensure that there is definitely no influence on the leader, he possesses a "talk only" radio exclusively. The information in this network can only flow from L to F and possible errors in the flow can be determined exactly. The influence weapon fires every time step, and according to the model setup, it possesses an attribute changer which changes the chosen attribute. For this analysis of errors transferred through the network, the single attribute changer is set to positive values only. To ensure that no information will get lost during a time step, the effectiveness of the communications between L and F is set to 100 %.

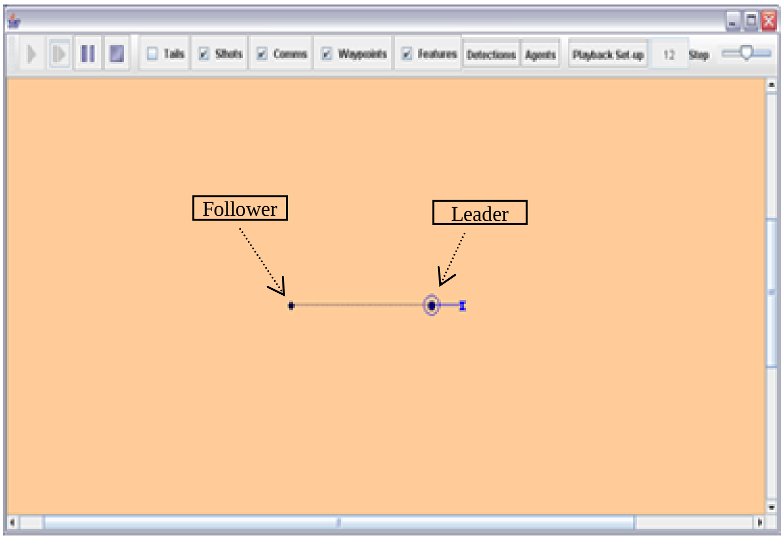

Figure 27. Rudimentary Simulation With Two Relevant Agents

The design of experiments is executed with the Nearly Orthogonal Latin Hypercube (NOLH) displayed in Figure 28. It is the same NOLH that Major Todd Ferris uses in his thesis for examining the analysis of the influences of Trigger Trains and Priority Lags. That makes the results and possible recommendations comparable.

Design Points	Factors			
	Attribute 1	Attribute 2	Attribute 3	Attribute 4
1	7	20	16	8
2	2	6	18	12
3	3	9	2	6
4	5	13	7	20
5	15	19	9	3
6	20	7	8	16
7	13	5	20	7
8	12	18	15	19
9	11	11	11	11
10	14	1	5	13
11	19	15	3	9
12	18	12	19	15
13	16	8	14	1
14	6	2	12	18
15	1	14	13	5
16	8	16	1	14
17	9	3	6	2

Figure 28. NOLH Used to Explore Simulation Model Behavior

Upper and lower values are chosen in conjunction with the idea of influence between participants in a social network and the limitations of Pythagoras 2.0.0. The variation of attributes falls within the range 0 to 1000, where the upper and lower values of 1 and 20 stand for 0.1% to 2%, respectively. So the agent's perception can be changed up to 2% in each time step with a direct influence. What is actually meant by influencing a person or subpopulation by 2% with a single action is not defined here. The maximum value of 20 is arbitrarily chosen and represents no real expression. Later studies may come up with more realistic values and appropriate ranges for attribute changes.

For the following analysis of the impeded errors in the social network representation, only Attribute 1 is varied.

B. THE EXPECTED VALUES

The first step toward identifying a possible error is to determine the values an agent should have in case of a disturbance-free simulation run. For this, the increase in attribute $\Delta(attribute)$ for each time step is added to the initial value $v(F_0)$ of the agent. This is a linear relationship for the leader and easy to calculate in EXCEL using the formula $v(L_1) = v(L_0) + \Delta(attribute)$. The formula given in the Pythagoras handout

[PM, Relative, 13.5.2.2] for the follower-values is $v(F_1) = v(F_0) + [v(L_0) - v(F_0)]*1\%$, where the 1% value represents the relative change of attributes through the communication channels. A graph for Run 1 with a positive attribute change of 7 is shown in Figure 29.

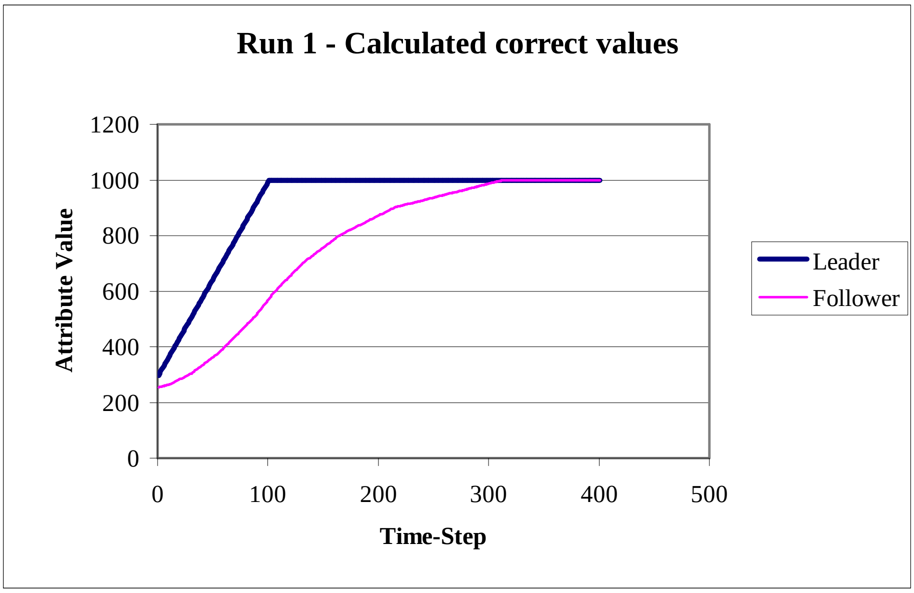

Figure 29. Run 1 – Calculated Correct Values of Leader And Follower

With only one positive influence on L, its values increase linearly until the maximum value for attributes of 1000. The attribute values of F change with positive slope every time step and have an inflection point when L reaches the max. Then F "catches up" and his value reaches the maximum value after approximately 320 time steps. There is no influence on F other than the communication between him and his leader. The change in F's attribute value is caused by the communication device, and demonstrates the influence the leader has on his subpopulation.

C. THE ACTUAL VALUES OUT OF THE SIMULATION RUNS

Different values for the attribute change result in different outcomes. These differences between changing the attribute by relatively small amounts compared to the results with higher amounts make some separate analysis necessary.

1. Small Attribute Changes

The term "small attribute change" is defined as a change from two to seven. In this range similar behavior of the agents is cognizable and can be analyzed.

The runs 1, 2, 3, 4, and 14 implement the attribute change values 7, 2, 3, 5, and 6, respectively. Run 4 with value 5 is the basis to show the ongoing processes in the model.

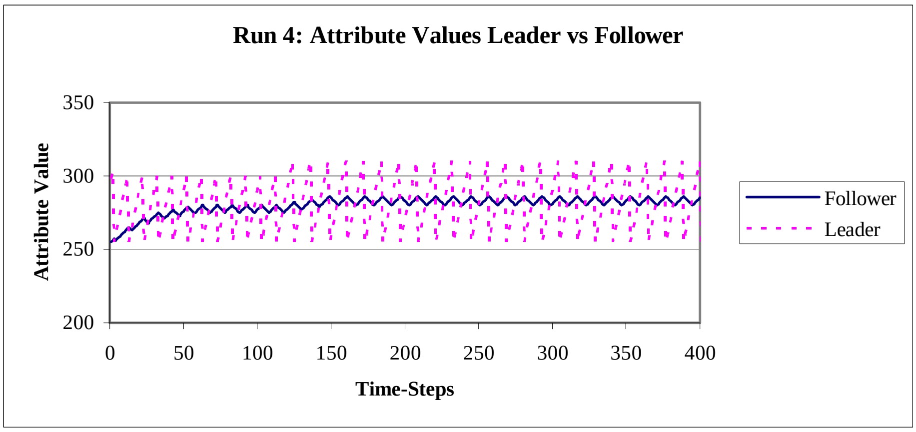

Figure 30. Actual Attribute Values Of Leader And Follower

Over the 400 time steps of the simulation run, the L is constantly influenced by the influential weapon which changes his attributes. When L reaches the upper threshold of 300 for the attributes, the trigger setting forces him into the color changing behavior for one time step and than back in his initial behavior. This entails resetting attributes to the value defined in the model implementation. The dotted line in Figure 30 shows this behavior.

After an sufficient amount of color change, L needs longer to reach the actual "blueness bin" representing his participation in the social networks as it takes more time steps for him to reach the upper threshold. The effects of "Trigger Train" and the "Priority Lag" can be seen from time step 120 to 122 (Figure 31).

timestep	Attribute1_F	Attribute1_L
108	277	290
109	278	295
110	279	300
111	280	255
112	279	260
113	278	265
114	277	270
115	276	275
116	275	280
117	276	285
118	277	290
119	278	295
120	279	300
121	280	305
122	281	310
123	282	255
124	281	260

Figure 31. Appearance of Trigger Trains and Priority Lag

Until time step 120, F reaches a maximum value of 280 in attributes, then he decreases due to the influence of L. When L needs longer to reset, the resulting higher attribute values of L result in higher values of F. But after L has reached the highest blueness for the particular run, he only trips between the attribute threshold values and pulls F back and forth. So, both L and F have reached steady oscillating patterns.

When the real attribute values of F will not increase further after a certain time step, there must be an error between the analytically derived values and the results from the simulation. To determine this error, the simulation values are compared with the analytic values and shown in Figure 32.

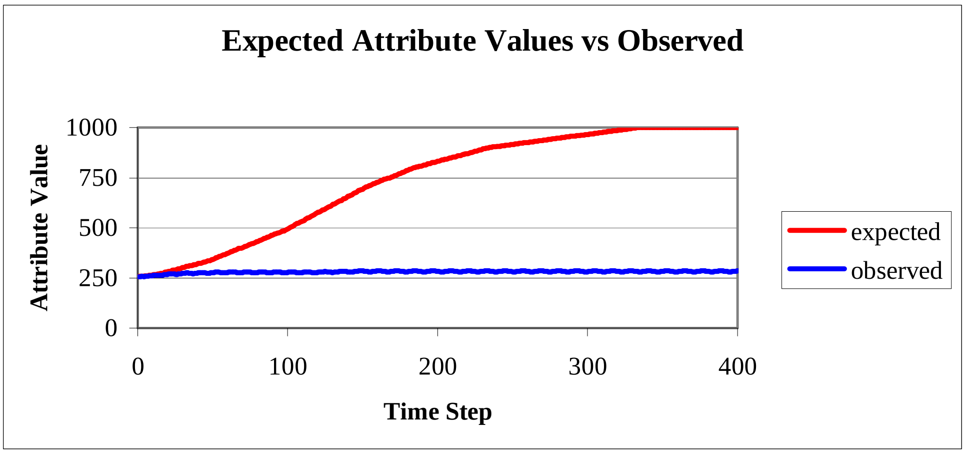

Figure 32. Comparison Of Expected Attribute Values vs Observed

In Run 4, the %-error between the desired attribute values and the actual values rises up to 72%. That means that the information passed through the social network is more than 70% off the true value (Figure 33).

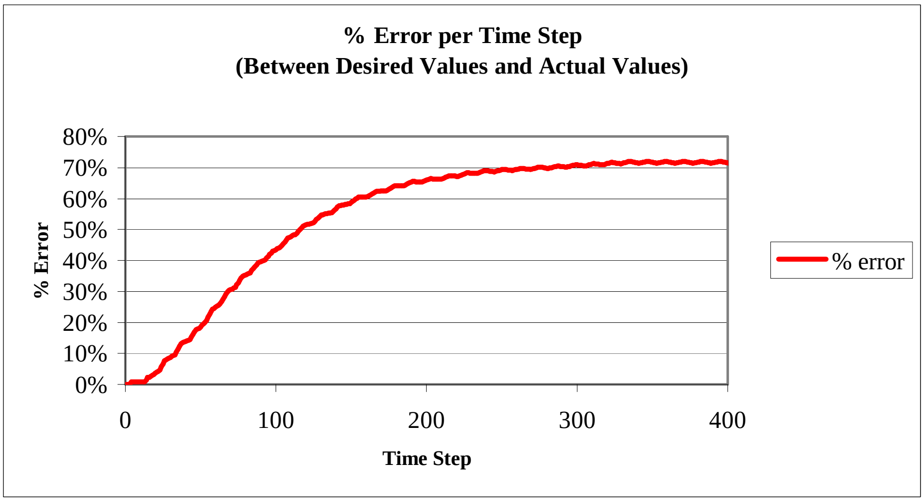

Figure 33. % Error per Time Step Between Desired And Actual Attribute Values

The analysis based on the average over all runs with small attribute changes yields a similar result, the mean % error per time step increases to 69% (Figure 34). The asymptotic closure to the maximum error value is a result of the Pythagoras implementation. As the true values reach the maximum, the observed values catch up until L and F reach the steady state.

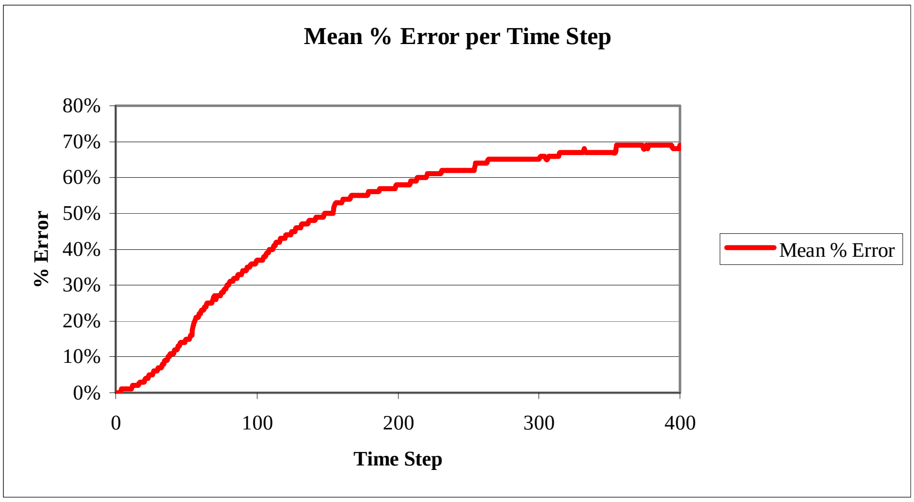

Figure 34. Mean % Error Per Time Step for Small Attribute Changes

This part of the analysis shows that the error resulting from the Pythagoras model implementation for a small change in attributes is too high to give reasonable outcomes.

2. Large Attribute Changes

As small changes in attributes with up to a delta of seven in attribute per time step cause unsatisfactory results, the model outcomes using large changes is analyzed.

The term "large attribute change" is used for a delta in attribute change between eight and 20. This range is wider than the range for small attribute changes because of the observable behavior of F. With large attribute changes, F reaches its own upper threshold of 300 and therefore the attribute value resets to the value defined in the model setup. This is not observable with small changes, and therefore eight is the defined cut between small and great changes.

In Run 16, with an attribute change value of eight per time step, the influences of Trigger Trains and Priority Lags on L becomes much greater than for the runs with a small attribute change. Recall that color triggers always have the highest priority and prevent other trigger events from being executed. Therefore the higher difference between the attribute of L and F is transferred through the network much more often. The attribute triggers cannot trip, but the influence is transferred through the network connections in every time step. So the attribute values of L have more time to pull F and therefore even F can reach the upper threshold for the attribute in this case; the appropriate trigger for F kicks in and the attribute value is reset. This is printed out in Figure 35.

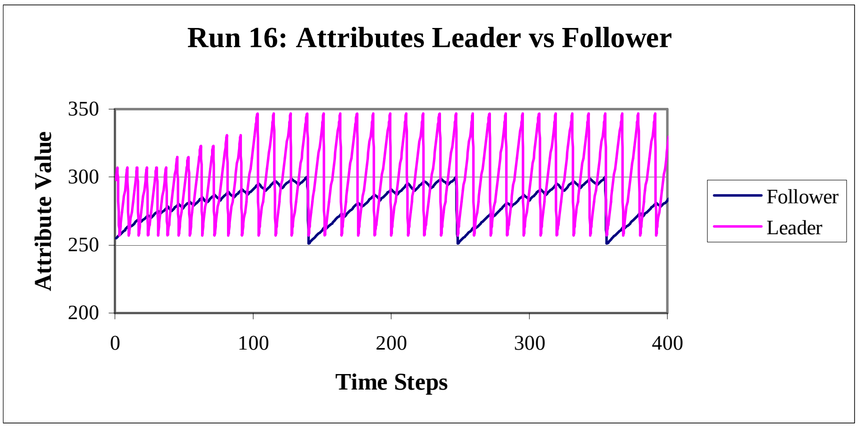

Figure 35. Actual Attributes of F and L for the "Large Attribute Change" Threshold

Because of this different behavior, it could be possible that there is a considerable difference in the resulting error between the small and large attribute change cases. But a comparison of Run 16 shows that the mean error (57%) over the entire run-time of the simulation is close to that of Run 4 (55%); the difference is marginal.

	Max % Error	Mean % Error
Run 4	72%	55%
Run 16	72%	57%

Table 6. Error Comparison Between Run 4 and Run 16

A comparison of both mean error curves shows that they have approximately the same maximum value (Figure 36). As expected, the higher changes result in a steeper curve and the maximum value is reached in fewer time steps. The maximum % error of approximately 70% can be considered the overall error of this model implementation. This shows that changing the size of the attribute change value does not result in a model with low error. The performance is completely unreasonable for both small and large attribute change values.

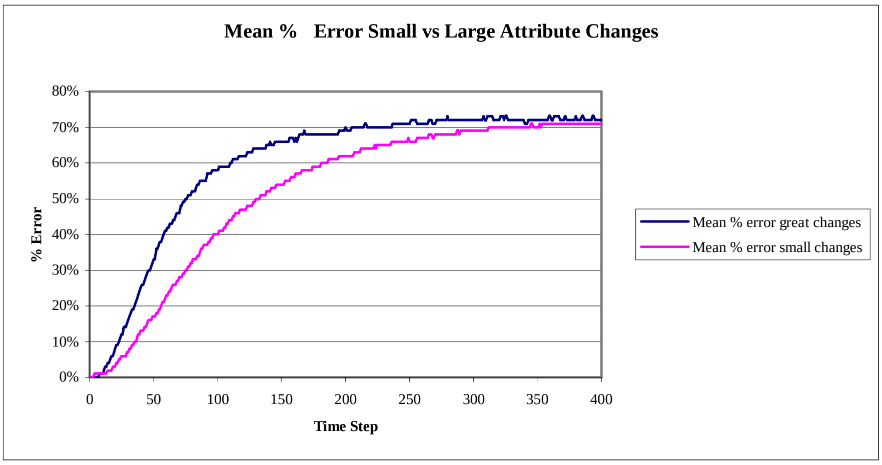

Figure 36. Mean % Error for Small vs. Large Attribute Changes

3. Results

Although the analysis considers only a very small and reduced social network, the results are transferable to the complete model because no characteristics of the model mapping are lost in the reducing process.

The results of this rudimentary social network analysis are:

- The error between the expected, true values for the attributes and the values from the simulation run rises fast, and reaches a maximum mean value of approximately 70%.
- There is no considerable difference detectable between the mean maximum values for small and large attribute changes.
- The agent representing the subpopulation can not reach the appropriate attribute value and gets stuck in an oscillating behavior.

In summary, the need to reset the attribute values to a pre-specified value after the color splash causes unfortunate effects in the social network. With the implemented methodology the analyzed, imbedded error between the true, desired behavior and what the model produces is drastic and unavoidable. There is no value for attribute changes that gives acceptable results, so one can say that Pythagoras 2.0.0 is incapable of building a reliable social network.

VI. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSIONS

The analytic models which are the basis for this study and the Pythagoras model are not complex. They express human behavior and the processes in a society in simplified formulas so that these can be implemented in a software. Usually it is "the beauty of simulation" (Prof. Lucas, NPS) that no complex algorithms in need of exact, predetermined inputs are needed to gain at least valuable insights to the given problem. It seems easy to map each of the analytic models individually in Pythagoras. But during the study and the modeling process it turned out that even simple models are not easy to represent in a time step simulation if they overlap. The interactions and dependencies among the different models are very difficult to capture, and what makes a calculation with pencil and paper hard can be even harder to model when they are incorporated into an existing software package designed to for different purposes. To understand the processes in a single human one needs several different models, depending on the situation. Even the results of a more complex model or algorithm cannot explain human behavior in depth. To find out what drives the attitude of a population and what are the most sensitive inputs it is necessary to use different models and theories. A single simulation like Pythagoras has too many limitations and restrictions to represent the behavior of a population. And using a scale of only 256 (0 to 255) color or 1001 (0 to 1000) attitude steps, it is not feasible to represent human behavior in depth—the scale is far too rough and inaccurate.

However, based on the three analytic models, Pythagoras can represent certain aspects of human behavior. It is a potentially useful tool for simulating stabilization operations to gain insights about which inputs are most valuable to vary. But the results should be used with extreme caution. While this study shows that there are some things Pythagoras clearly can represent, there are other things that are definitely not doable with the version we used.

Because Pythagoras is a combat model, it can easily represent all parts of a stabilization operation that are related to any kind of military actions. Patrolling areas, hunting down terrorists, responding to terrorist attacks, and so forth are easily to model; this part of the attitudinal model is well-modeled. Even global actions that influence a population like mass media or taxes can be modeled and analyzed, whether the entire populace is under this influence at the same time or only parts of it in different locations are affected. So influences from the outside that act on single agents, groups of agents, or all agents at once can be mapped.

But there are other aspects of a stabilization operation and human behavior that are not easy to map. It is not possible to represent the duration of a perceived action for a single agent. Because of the movement of the agents, one can not ensure that the acting agent (e.g., a terrorist) meets the influenced agent later on in the simulation to take away the amount of influence he delivered earlier. That would be necessary to implement a memory function and to meet the requirement of the attitudinal model. Also, Pythagoras's nature as a time step model causes another, bigger problem. One cannot implement a slowly fading memory as occurs in real life. A human does not forget from one second to the other, but his memories wash out over time. In Pythagoras the best thing to do to implement memory is to take away some or all of the influence delivered earlier. Thus the memory of a human or a subpopulation is not a smoothly decreasing function but a step function in this model. This is clearly far away from real life.

With the current version of Pythagoras we could not construct a proper social network representation. Due to the necessary reset of attitudes after a color change, the information transferred through the social network is inaccurate. The limitations of the current software make it impossible to realize an accurate social network representation and therefore some more code changes are needed to represent and analyze the interactions of a populace.

Most parts of the attitudinal model can be represented to a reasonable degree of accuracy, but this is not true for the other two models. A social network can be mapped with the communications devices of Pythagoras, but the results are not useful as pointed out. The economical parts of the insurrection model are difficult to model, because

Pythagoras has no features implemented to represent economics. The resources device is not entirely sufficient, because it is not in the nature of a combat model to supply the enemy. But in a economic model it should be possible to support an enemy to influence him, say by paying money or passing other items to him. Wealth could determine how quickly an agent switches to another economic sector if his net income from production disappears. Also, in the current economic model, taxes are simply a drain on family resources. In order to model long-term stabilization operations, a link between the taxes collected and beneficial actions (like infrastructure improvement) may be necessary. Without this option, a complete economy with all ongoing transactions cannot be represented with the current version.

Some of the difficulties we face in constructing the simulation model are manageable. What we call the Priority lag can be minimized by choosing small values for the attribute changes. It may be reasonable to assume that in corresponding real life situations that the impact on a human's behavior is only small, so even without recommended software changes the results are within an acceptable error range. The same is true for Trigger Trains; by reducing the fidelity of the model and the number of social network bins, the results will be in an acceptable range. Unfortunately, not all issues can be dealt with by careful choice of model coefficients or using modeling tricks. An example is the so-called Trigger Tree. We found out that there is no feasibility with any fidelity. To avoid the implementation of exponential growing trigger options, we had to set the agent back to his initial behavior with all previously described consequences. Worst of all are the problems for the Social Networks. Because we must send an agent back to "Initial" and we must enter trigger set bounds, we need to "Reset" the attribute that actually trips. With this reset to an arbitrary value, the social network is ineffective.

For these reasons we recommend some crucial software changes. These will help future modelers to overcome at many, but certainly not all, of the problems we faced.

B. RECOMMENDATIONS

After implementing all three analytical models and conducting test runs, it turns out that Pythagoras has some weaknesses, restrictions and limitations. These cause the problems described in this study and keep the model from producing useful data. The research discovered a couple of possible developments and software changes that can overcome these limitations. Even if it not foreseeable when and how these changes can be realized, it would enhance the possibilities to represent human behavior with Pythagoras 2.0.0.

Recommended changes relate to:

- terrain visibility
- movement desire
- attribute weights entry
- the "Suicide Agent"
- trigger option settings
- extension of trigger name eligibility.

Detailed discussions of these improvements follow.

Terrain visibility. As of today in Pythagoras 2.0.0 an agent is only able to see the terrain on adjacent pixels. At every time step, he checks to see which of these pixels have terrain defined as more preferable (i.e., with some better characteristics such as ease of movement) and which have terrains the agent should avoid. Therefore an agent can choose better terrain and proceed there, or avoid the less-preferable terrain. To use terrain features to control the agent's movement, a software change is recommended to widen the view of the agent. An agent should be able to see terrain far away from his current position. Then he can decide to go there or not. There are clear benefits for representing urban cultural geography: if an agent changes his attitude and recognizes the "correct" terrain (the soldering, insurgent or production sector) according to his new attitude, he can straight go there. So it would not be necessary to invent alternate and creative methods to implement movement towards the desired economic sector.

Movement desire. The agent set-up tab "Movement Desire" should contain an entry option that forces the agent to move towards another terrain. This entry in the

"Title" column must have multiple alternatives to chose the desired movement like the "Toward Friend …" in the current version. These alternatives could be

- Toward terrain if movement is different
- Toward terrain if concealment is different
- Toward terrain if … is different

This code change is only useful in cases where the agent gets an increased terrain visibility and, therefore, knows from the distance where to find better terrain. The term "different" stands for all useful changes in terrain characteristics. It can be better, worse, a ratio, a difference, or an absolute value. In combination with advanced terrain visibility, a modeler will have the opportunity to control an agent via terrain and, depending on the situation, can send him to interesting places, buildings or sectors. This gives the modeler more flexibility than the current mode of using waypoints. Especially in models dealing with biological or chemical contamination, destroyed or otherwise hazardous areas advanced terrain visibility could be useful for long distance decisions of an agent.

Attribute weights entry additional entries for width and weights of the attributes should be available on the "Attributes" agent setup tab. These entries must be linked to color and the conversion from attribute change to color change must be done "behind the scenes." Then a modeler can define the attribute's weight, which expresses the attribute's importance for an agent when compared to the other attributes' weights. Every time the attribute values change in the simulation, the color should automatically change according to the proposed formula:

$$color = \sum_{i=1}^{10} \left(value\, attribute\, i \right) * \left(weight\ attribute\, i \right)$$

where i is the activated attribute. Weights are zero for attributes that are not used. Another check box should select the color to change.

The "Suicide Agent." An agent should be capable of changing his own color according to his situation, in other ways than are currently implemented on the agent setup "Side Property." The current options depend on combat situations like shooting or being shot at. The actual Pythagoras version is not designed to allow an agent to hurt or kill himself. But to represent human behavior it must be possible to commit suicide in certain situations. An agent should be able to change his own color or attributes via a weapon and shoot himself. Therefore a code change is recommended that allows a weapon to be used against the agent who possesses this weapon. With this code change an agent can cause the appropriate change in color or attributes to trigger himself into an alternate behavior.

Trigger option settings. The threshold for "Trigger Event Values" allows only a fixed value for a trigger event. This is the reason that the attribute value must be reset to a predefined value after a trigger event occurred. Without this reset, the attribute value would always stay above the threshold and this trigger would trip in each time step. The recommended code change would allow the modeler to define a range instead of a fixed value as trigger event. Whenever the defined attribute delta is added or subtracted from the attribute value, the trigger event would occur. Thus an attribute's values could be updated throughout the simulation run without being reset to a predetermined chosen value. So the exact attribute value would be transferred through the communication channels, and the social network representation would work more accurately.

Extension of trigger name eligibility. Adding the option to chose the same "Trigger Name" multiple times from a pull down list on the agent set-up tab "Triggers" would eliminate the "Trigger Trains" in the model. Every time the agent is reset to his "Initial Behavior" after a color splash, he has to go on the long march until he reaches his proper color bin, representing the proper network and participation distribution settings. With the current version of the software, the agent has to step to a new bin, check to see if this is the right one according to his color value, and proceed to the next bin in the next time step if not. If, for example, the "Trigger Name" column could contain multiple entries with the corresponding alternate behavior, then the agent could proceed directly into the proper bin. Mandatory for this to work is either a range [min value, max value] for, e.g., blueness, or an entry in the pull down list like "blueness between … and …". In either case, two additional columns are necessary to define the minimum and maximum values.

Priority setting. The priority setting in the agent setup tab "Triggers" should allow several attribute or color changes to share the same priority. With this feature, it can be ensured that all events with equal priority will contribute to a change and no attribute or color change will get lost or be represented inaccurately. This can only be implemented for events that contribute to a change in the agent's attributes, colors or other issues.

Because an agent can only be in a unique behavior at a time, only one alternate behavior can be triggered in any time step. Thus the recommended code change is not to eliminate the priority option, but to enhance the priority setup options.

C. SUMMARY

Human behaviors and interactions in social networks are complicated processes and not easy to predict or to model. In fact there exist several analytical models and theories, and each of these explain a proportion of single human behavior or activities in social networks accurate and with reasonable results. And often complex models were developed to explain these complicated processes in a single simulation. But do these models take in account all interactions and dependencies? This study combines three analytical models to find out if a single software can handle interactions between different theories and can represent at least simple human behavior. It is the benefit of this study to show that even the transfer of easy looking models in an advanced software brings unpredictable difficulties; and that the intersections and mutual influences in a society are hard to map.

The results and findings of this study show a way to enhance the capabilities of Pythagoras 2.0.0, so the software could be used by the U.S. Army and Marine Corps for more sophisticated analyses of stabilization operations. But they also demonstrates that it might be better to use more than one simulation software platform—along with more than one version of any subcomponent analytic models—to represent and predict human behavior.

Finally, this study shows that experimental design is a valuable tool during model development. It allows the analyst to explore a wide variety of situations and identify those that need to be investigated in greater detail. In the end, this will help the decision maker to come up with better decisions regarding stability operations and other issues critical to global security.

APPENDIX A: ATTITUDE EFFECT MODEL WORKING PAPER

A Model for the Effect of Host Nation/Insurgency Operations on a Population

By

P. A. Jacobs
D. P. Gaver
M. Kress
R. Szechtman

1. Model Overview

There are K *actors*; examples of actors are a host nation, group of insurgents, the outside stability forces, the militias, outside military forces that do not support the host nation, etc.

There are S *subpopulations* (homogenous groups of people); examples of subpopulations are a tribe whose members believe in the same religion and who reside in a particular location; the (sub)collection of people who attend a particular mosque and tend to share common cultural features or in a certain neighborhood in a major city.

The actors take actions against each other and against the subpopulations; examples of actions are assassinations, job creation in a location, maintenance of police presence in a neighborhood, etc. The subpopulations do not take actions. The *effect* of an actor's action has a duration during which the subpopulations perceive the action as being good (helpful) or bad (hurtful). The result of the subpopulations' perceptions of the actions may be changes of their attitude towards certain actors.

2. A Specific Model

There are S subpopulations. There are two actors—the host nation (H) and the insurgency (I)—and S subpopulations, $s \in \{1, 2..., S\}$, each either supports H or I. A supporter of H (respectively I) opposes I (respectively H). Each actor generates actions; in the present model there is only one kind of action for each actor; the actions themselves are not labeled as good or bad. However, each action by an actor is perceived by a subpopulation as being good or bad; degrees of "goodness" and "badness" are not represented in the current model. The perception of each actor's actions by a subpopulation influences the attitude of the subpopulation towards the actor. The attitudinal effect of an action on subpopulation s has a limited duration; the actions affect attitudes in a subpopulation through media reporting, word of mouth and personal exposure to the effect of the action such as destruction/repair of local infrastructure, job loss/creation, etc. An action is called *active* at time t if it is still influencing subpopulation attitude (pro/anti H, etc.) at time t. This model assumes that an entire subpopulation responds simultaneously and homogenously to actions and their effects.

Let $G_H(s,t) \geq 0$, (respectively $B_H(s,t) \geq 0$), be the mean number of active H-actions perceived as good, (respectively bad), by subpopulation s at time t. Let $G_I(s,t) \geq 0$, (respectively $B_I(s,t) \geq 0$), be the mean number of active I-actions perceived as good, (respectively bad), by subpopulation s at time t.

Model Premise:

Active H-actions perceived as good by subpopulation s and active I-actions perceived as bad by subpopulation s encourage subpopulation s to support H. Active H-actions perceived as bad by subpopulation s and active I-actions perceived as good by subpopulation s encourage subpopulation s to support I.

Let $p_s(t)$ be the measure of subpopulation *s* support for H at time t; $0 \leq p_s(t) \leq 1$. The measure of subpopulation s support for I is $1 - p_s(t)$ If $p_s(t)$=1 then subpopulation s strongly supports H; if $p_s(t)$=0 then subpopulation s strongly supports I

. Let $y_s(t)=\log\left[\frac{p_s(t)}{1-p_s(t)}\right]$, the log odds of the measure that population s supports H at time t; $y_s(t)\in(-\infty,\infty)$; large positive values reflect support for H and negative values reflect support for I. Let $\underline{y}(t)=(y_1(t),...,y_S(t))$, the vector of log odds for all the sub-populations. This vector represents the subpopulations' attitudes towards H and I.

Model 1:

Parameters

Constant rate at which H initiates actions	λ_H
Constant rate at which I initiates actions	λ_I
The probability an H-action is perceived as good (respectively as bad) by subpopulation s at time t. This probability may depend on the attitude of other subpopulations.	$0\le\gamma_H(s,\underline{y}(t))\le 1$ (respectively $1-\gamma_H(s,\underline{y}(t))\equiv\bar{\gamma}_H(s,\underline{y}(t))$)
The probability an I-action is perceived as good (respectively as bad) by subpopulation s at time t.	$0\le\gamma_I(s,\underline{y}(t))\le 1$ (respectively $1-\gamma_I(s,\underline{y}(t))\equiv\bar{\gamma}_I(s,\underline{y}(t))$)
The mean time an H-action perceived by subpopulation s as good (respectively bad) remains active with respect to subpopulation s.	$1/\mu_{HG}(s)\ge 0$ (respectively $1/\mu_{HB}(s)\ge 0$)
The mean time an I-action perceived by subpopulation s as good (respectively bad) remains active with respect to subpopulation s.	$1/\mu_{IG}(s)\ge 0$ (respectively $1/\mu_{IB}(s)\ge 0$)
Coefficient that translates the number of active H-actions perceived as good (respectively bad) by subpopulation s into attitude change in that subpopulation; (see Eq. 2).	$\xi_{HG}(s,\underline{y}(t))\ge 0$ (respectively $\xi_{HB}(s,\underline{y}(t))\ge 0$)
Coefficient that translates the number of active I-actions perceived as good (respectively bad) by subpopulation s into attitude change in that subpopulation;(see Eq 2).	$\xi_{IG}(s,\underline{y}(t))\ge 0$ (respectively $\xi_{IB}(s,\underline{y}(t))\ge 0$)
Initial attitude of subpopulation s towards H	a_s

Equations for the Mean Number of Active Actions:

$$\underbrace{G_H(s,t+h)}_{\substack{\text{Mean number}\\ \text{of active}\\ \text{H-actions}\\ \text{perceived as}\\ \text{good by}\\ \text{subpopulation s}\\ \text{at time t+h}}}=\underbrace{G_H(s,t)}_{\substack{\text{Mean number}\\ \text{of active}\\ \text{H-actions}\\ \text{perceived as}\\ \text{good by}\\ \text{subpopulation s}\\ \text{at time t}}}+\underbrace{\lambda_H\gamma_H(s;\underline{y}(t))h}_{\substack{\text{Mean number}\\ \text{of actions by H}\\ \text{that are perceived}\\ \text{as good by}\\ \text{subpopulation s}\\ \text{that occur during}\\ \text{during time (t,t+h]}}}-\underbrace{\mu_{HG}(s)G_H(s,t)h}_{\substack{\text{Mean number of}\\ \text{actions by H that}\\ \text{are perceived as}\\ \text{good by subpopulation s}\\ \text{that stop being active}\\ \text{(are forgotten)}\\ \text{during (t, t+h]}}} \qquad (1a)$$

$$\underbrace{B_H\left(s,t+h\right)}_{\substack{\text{Mean number}\\ \text{of active}\\ \text{H-actions}\\ \text{perceived as}\\ \text{bad by}\\ \text{subpopulation s}\\ \text{at time t+h}}} = B_H\left(s,t\right)+\lambda_H\overline{\gamma}_H\left(s;\underline{y}\left(t\right)\right)h-\mu_{HB}\left(s\right)B_H\left(s,t\right)h \tag{1b}$$

$$\underbrace{G_I\left(s,t+h\right)}_{\substack{\text{Mean number}\\ \text{of active}\\ \text{I-actions}\\ \text{perceived as}\\ \text{good by}\\ \text{subpopulation s}\\ \text{at time t+h}}} = G_I\left(s,t\right)+\lambda_I\gamma_I\left(s;\underline{y}\left(t\right)\right)h-\mu_{IG}\left(s\right)G_I\left(s,t\right)h \tag{1c}$$

$$\underbrace{B_I\left(s,t+h\right)}_{\substack{\text{Mean number}\\ \text{of active}\\ \text{I-actions}\\ \text{perceived as}\\ \text{bad by}\\ \text{subpopulation s}\\ \text{at time t+h}}} = B_I\left(s,t\right)+\lambda_I\overline{\gamma}_I\left(s;\underline{y}\left(t\right)\right)h-\mu_{IB}\left(s\right)B_I\left(s,t\right)h \tag{1d}$$

Example initial conditions: $G_H\left(s,0\right)=0, B_H\left(s,0\right)=0, G_I\left(s,0\right)=0, B_I\left(s,0\right)=0$ for $s\in\{1,2,...,S\}$.

Example for γ_H and γ_I:

$$\gamma_H\left(s,\underline{y}\left(t\right)\right)=p_s\left(t\right);\gamma_I\left(s,\underline{y}\left(t\right)\right)=1-p_s\left(t\right). \tag{1e}$$

In this example the more support subpopulation s has for H (respectively I) the more likely it is to perceive H-actions as good (respectively bad) and I-actions as bad (respectively good).

The measure of subpopulation s support for H at time 0 is $y_s\left(0\right)=a_s$. The constant a_s represents the basic support of sub-population s for H; if a_s is large and positive the basic support for H is strong; if a_s is negative then the basic support for H is weak.

The Equation for Subpopulation Attitude Changes.

$A_s\left(t\right)$ is a measure of the attitude change of subpopulation s towards the actors H and I at time t with respect to its basic attitude measure a_s. $A_s\left(t\right)$ is a function of the subpopulation's perceptions of the actions still in effect and the current attitudes $\underline{y}(t)=(y_1(t),...,y_S(t))$ of the other subpopulations. The subpopulation s has a basic attitude towards H measured by a_s.

For positive constants $\xi_{HG}(s,\underline{y}(t)),\xi_{HB}(s,\underline{y}(t)),\xi_{IG}(s,\underline{y}(t)),\xi_{IB}(s,\underline{y}(t))$ the change in the attitude of subpopulation s due to active actions and the attitudes of other subpopulations evolves as

$$
\begin{aligned}
\underbrace{A_s(t+h)}_{\substack{\text{Attitude}\\ \text{towards H}\\ \text{at time t+h}\\ \text{due to}\\ \text{active actions}}} = \underbrace{A_s(t)}_{\substack{\text{Attitude}\\ \text{towards H}\\ \text{at time t}\\ \text{due to}\\ \text{active actions}}} \\
&+ \underbrace{\xi_{HG}(s,\underline{y}(t))G_H(s,t)h}_{\substack{\text{Mean change in attitude}\\ \text{towards H}\\ \text{by subpopulation s during (t,t+h]}\\ \text{that is due to active}\\ \text{H-actions that are perceived}\\ \text{as good}}} - \underbrace{\xi_{HB}(s,\underline{y}(t))B_H(s,t)h}_{\substack{\text{Mean change in attitude}\\ \text{towards H}\\ \text{by subpopulation s during (t,t+h]}\\ \text{that is due to active}\\ \text{H-actions that are perceived}\\ \text{as bad}}} \\
&+ \underbrace{\xi_{IB}(s,\underline{y}(t))B_I(s,t)h}_{\substack{\text{Mean change in attitude}\\ \text{towards H}\\ \text{by subpopulation s during (t,t+h]}\\ \text{that is due to active}\\ \text{I-actions that are perceived}\\ \text{as bad}}} - \underbrace{\xi_{IG}(s,\underline{y}(t))G_I(s,t)h}_{\substack{\text{Mean change in attitude}\\ \text{towards H}\\ \text{by subpopulation s during (t,t+h]}\\ \text{that is due to active}\\ \text{I-actions that are perceived}\\ \text{as good}}} \\
&+ \underbrace{\sum_{j\neq s}\kappa_{sj} f(y_s(t),y_j(t))h}_{\substack{\text{Mean change in attitude}\\ \text{towards H}\\ \text{by subpopulation s during (t,t+h]}\\ \text{due to influence of other}\\ \text{subpopulations}}}
\end{aligned}
\tag{2}
$$

Example of initial condition: $A_s(0)=0$ for $s\in\{1,2,...,S\}$.

Example for specification of $\xi_{HG},\xi_{HB},\xi_{IG},\xi_{IB}$:

$$
\begin{aligned}
&\xi_{HG}(s,\underline{y}(t))=(1-p_s(t)),\xi_{HB}(s,\underline{y}(t))=p_s(t),\\
&\xi_{IG}(s,\underline{y}(t))=p_s(t),\xi_{IB}(s,\underline{y}(t))=(1-p_s(t))
\end{aligned}
\tag{3a}
$$

The greater the support for I (respectively H) in a subpopulation, the greater is the mean change in the attitude of the subpopulation towards H that are due to H-Actions that are perceived as good (respectively bad). The greater the support for I (respectively H) in the subpopulation, the greater is the mean change in subpopulation attitude towards H as a result of I-Actions that are perceived as bad (respectively good). There are other possibilities.

Examples for the other subpopulation influence function f:

Let S_s be the (constant) size of subpopulation s

$$f\left(y_s, y_j\right) = \frac{S_s}{S_s + S_j} y_s + \frac{S_j}{S_s + S_j} y_j ; \tag{3b}$$

the mean change in attitude towards H due to the attitude of another subpopulation depends on the relative sizes of the two populations.

$$f\left(y_s, y_j\right) = \frac{e^{\left|a_s - a_j\right|}}{1 + e^{\left|a_s - a_j\right|}} y_j + \frac{1}{1 + e^{\left|a_s - a_j\right|}} y_s ; \tag{3c}$$

the mean change in attitude towards H due to the attitude of another subpopulation depends on how close their basic attitudes towards H are.

Other examples are possible.

The total attitude of subpopulation s at time t towards H is

$$y_s\left(t\right) = a_s + A_s\left(t\right) \tag{4}$$

Therefore, the measure of subpopulation s support for H at time t is

$$p_s\left(t\right) = \frac{e^{\left[a_s + A_s(t)\right]}}{1 + e^{\left[a_s + A_s(t)\right]}} \tag{5}$$

Example 1: A Model with One subpopulation and No Feedback

There is one subpopulation. All of the coefficients in the equations are constants, (do not depend on $\underline{y}\left(t\right)$). In particular γ_I and γ_H are constants. Letting $t \to \infty$ in equations (1a-1d) results in

$$G_H\left(\infty\right) = \lambda_H \gamma_H \frac{1}{\mu_{HG}} \tag{6a}$$

$$B_H\left(\infty\right) = \lambda_H\left[1 - \gamma_H\right] \frac{1}{\mu_{HB}} \tag{6b}$$

$$G_I(\infty) = \lambda_I \gamma_I \frac{1}{\mu_{IG}} \tag{6c}$$

$$B_I(\infty) = \lambda_I [1-\gamma_I] \frac{1}{\mu_{IB}} \tag{6d}$$

The limiting mean number of active H-actions that are perceived to be good (respectively bad) is $\frac{\lambda_H \gamma_H}{\mu_{HG}}$ (respectively $\frac{\lambda_H (1-\gamma_H)}{\mu_{HB}}$). The limiting mean number of active I-actions that are perceived to be good (respectively bad) is $\frac{\lambda_I \gamma_I}{\mu_{IG}}$ (respectively $\frac{\lambda_I (1-\gamma_I)}{\mu_{HB}}$).

The limiting mean change in attitude during a time period of length h due to active H-actions perceived as good (respectively bad) is $c_{HG} = \xi_{HG} \frac{\lambda_H \gamma_H}{\mu_{HG}} h$ (respectively $c_{HB} = \xi_{HB} \frac{\lambda_H (1-\gamma_H)}{\mu_{HB}} h$). The limiting mean change in attitude during a time period of length h due to active I-actions perceived as good (respectively bad) is $c_{IG} = \xi_{IG} \frac{\lambda_I \gamma_I}{\mu_{IG}} h$ (respectively $c_{IB} = \xi_{IB} \frac{\lambda_I (1-\gamma_I)}{\mu_{IB}} h$).

If the limiting mean change in attitude due to active actions that support H is greater than the limiting mean change in attitude due to active actions that support I:

$$c_{HG} + c_{IB} > c_{HB} + c_{IG}$$

then as $t \to \infty$ the measure of support, $p(t)$, of the subpopulation for H tends to 1.

Discussion: The limiting mean change in attitude depends on the mean time an action remains in active; whether or not an H-action is perceived as good and an I-action is perceived as bad by the sub-population; and the rate at which perceived active actions influence the attitude of the subpopulation. If the sum of mean attitude change due to active H-actions that are perceived by the sub-population as good and active I-actions that are viewed by the sub-population as bad is greater than the sum of the mean attitude change due to active H-actions are viewed as bad and active I-actions that are viewed as good, then in the long run the subpopulation will support H.

Example 2: A Model with One Subpopulation and Feedback

There is one subpopulation. We assume

$$\gamma_H\left(s,\underline{y}(t)\right)=p_s(t);\gamma_I\left(s,\underline{y}(t)\right)=1-p_s(t);$$

that is, the greater the support the subpopulation has for H (respectively I) the more likely the subpopulation will perceive H-actions as good (respectively bad) and I-actions as bad (respectively good). The other parameters are constants.

Letting $t\to\infty$ in equations (1a-d) results in

$$G_H(\infty)=\frac{\lambda_H}{\mu_{HG}}\frac{e^{a+A(\infty)}}{1+e^{a+A(\infty)}} \tag{7a}$$

$$B_H(\infty)=\frac{\lambda_H}{\mu_{HB}}\frac{1}{1+e^{a+A(\infty)}} \tag{7b}$$

$$G_I(\infty)=\frac{\lambda_I}{\mu_{IG}}\frac{1}{1+e^{a+A(\infty)}} \tag{7c}$$

$$B_I(\infty)=\frac{\lambda_I}{\mu_{IB}}\frac{e^{a+A(\infty)}}{1+e^{a+A(\infty)}} \tag{7d}$$

Discussion: The effect of the actions depends on the mean number of actions initiated during a period, $\lambda_\bullet h$; the mean change in subpopulation attitude resulting from active actions during each period which is influenced by $\xi_{\bullet,\bullet}h$; and the mean duration time the actions remain active, $1/\mu_{\bullet,\bullet}$. It also depends on the basic attitude of the subpopulation, $a_\bullet$ at time 0.

Some numerical examples

H can control the rate at which its actions are initiated subject to availability of resources. H can also influence, though publicity and control of the media, the mean time active time of actions perceived by the population as enhancing support for H (H-actions perceived as good and I-actions perceived as bad).

Figure 1 displays the measure of support for H as a function of time for three values of basic attitude towards H at time 0, a. The rate at which actions are initiated and their effect on the subpopulation are equal for H and I. In this case the initial basic support for H determines the limiting measure of support H has.

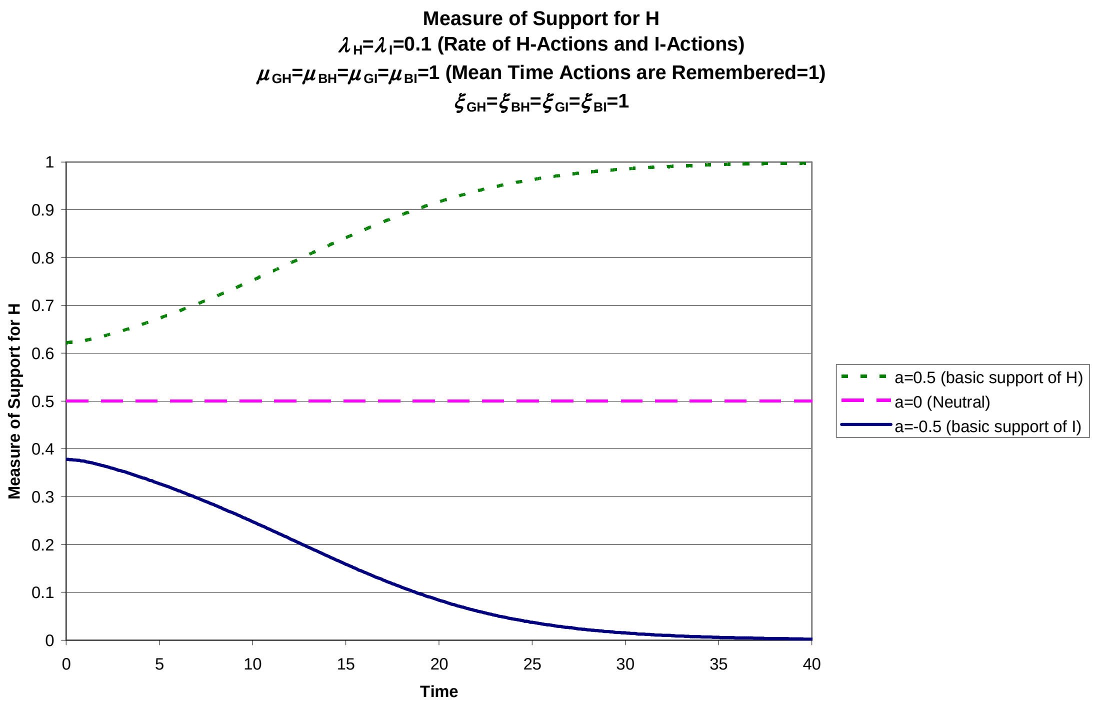

Figure 1

Figure 2 displays the measure of support for H as a function of time for different mean active times actions supporting H (H-actions perceived as good and I-actions perceived as bad) are remembered (active). At time 0 the subpopulation's basic support is for I ($a = -0.5$). The mean active time of actions supporting I (H-actions perceived as bad and I-actions perceived as good) are equal to 1 in all cases. Figure 2 suggest the larger the mean time active time of actions supporting H are remembered (relative to the mean time active time of actions supporting I are remembered), the more likely the subpopulation will support H.

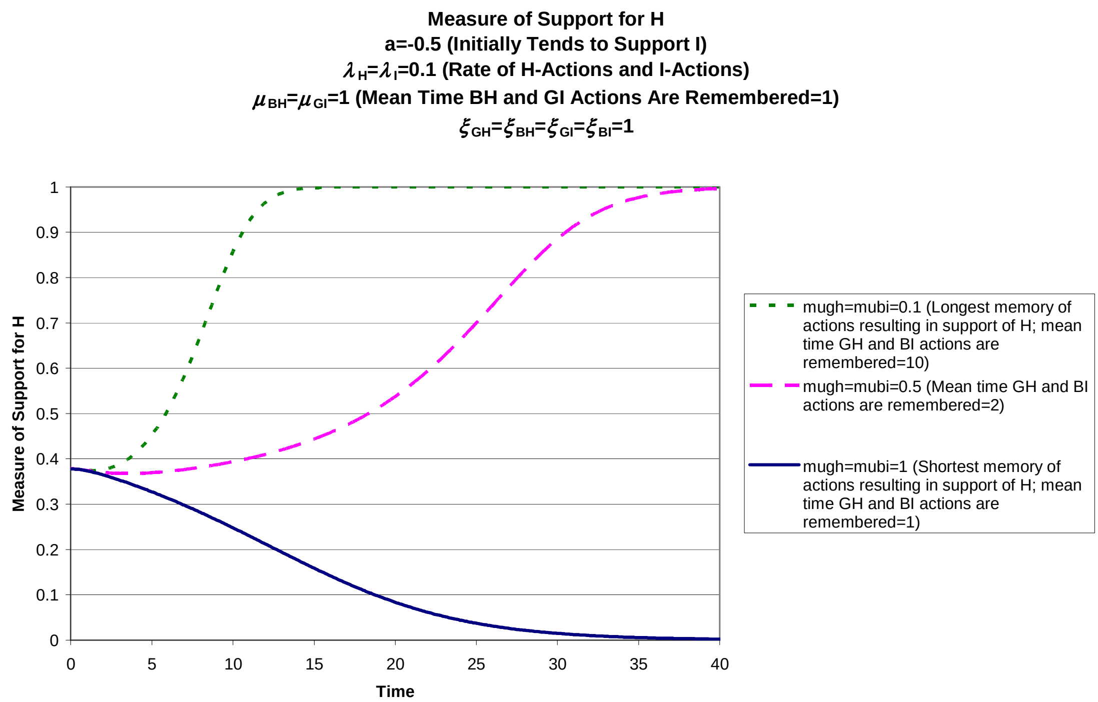

Figure 2

Figures 3a-3c display the measure of support for H as a function of time for different rates at which H takes actions and different mean active times of actions supporting H (H-actions perceived as good and I-actions perceived as bad). At time 0, the subpopulation has basic support for I. The rate of I-actions is 0.1 in all cases. The mean active time of actions supporting I (H-actions perceived as good and I-actions perceived as bad) is 1 in all cases. Figure 3a suggests that increasing the rate at which H-actions are taken without increasing the mean active time of actions supporting H does not overcome the initial support for I. In Figure 3b the rate at which H takes actions are the same as those as Figure 3a but the mean active time of actions supporting H are doubled from 1 to 2. In this case the smallest rate of H-actions results in H gaining the support of the subpopulation; the two larger rates result in the subpopulation strengthening its support for I. Apparently, this is because initially the majority of H-actions are perceived as bad and larger H-action rates incur more actions that are perceived as bad; the memory of actions that support H is not long enough to overcome the initial perception. In Figure 3c the mean active time of actions supporting H are remembered is further increased to 10. In this case H gains support of the subpopulation for each of the H-actions rates considered. There is also a suggestion if the rate of H-actions is large, then support for H may initially decline until the mean number of active actions supporting H increases enough to overcome the initial support for I.

Measure of Support for H
a=-0.5 (Initially Tends to Support I)
λ_I=0.1 (Rate of I Actions)
μ_{GH}=1, μ_{BI}=1 <u>(Mean Time GH and BI Actions are Remembered=1)</u>
μ_{BH}=μ_{GI}=1 (Mean Time BH and GI Actions are Remembered=1)
ξ_{GH}=ξ_{BH}=ξ_{GI}=ξ_{BI}=1

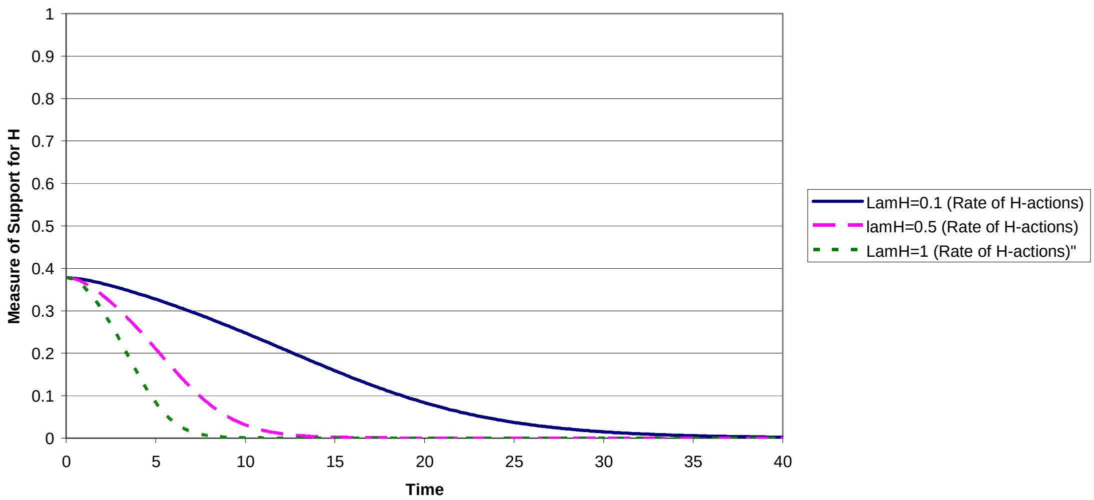

Figure 3a

Measure of Support for H
a=-0.5 (Initially Tends to Support I)
λ_I=0.1 (Rate of I-Actions)
μ_{GH}=0.5, μ_{BI}=0.5 <u>(Mean Time GH and BI Actions Are Remembered=2)</u>
μ_{BH}=μ_{GI}=1(Mean Time BH and GI Actions Are Remembered=1)
ξ_{GH}=ξ_{BH}=ξ_{GI}=ξ_{BI}=1

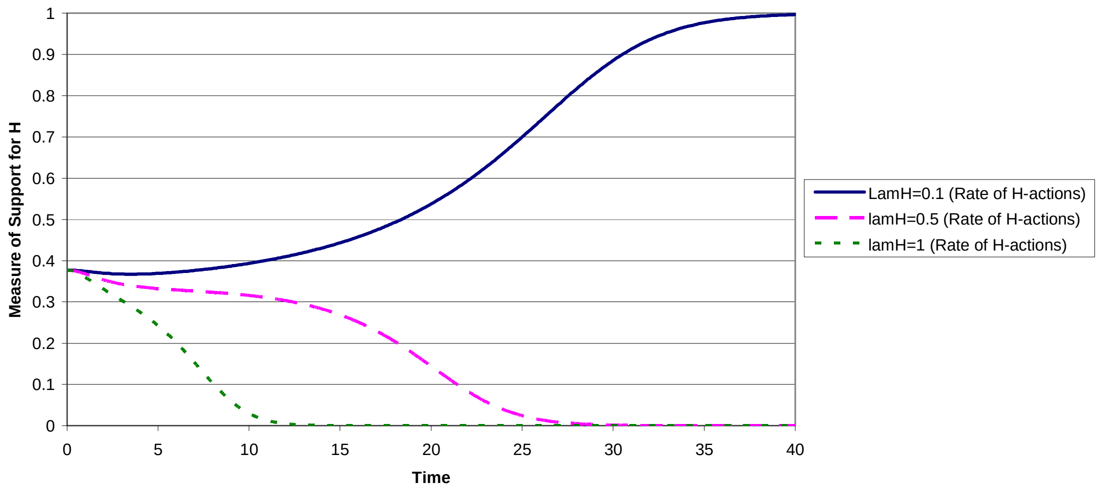

Figure 3b

Measure of Support for H
a=-0.5 (Initially Tends to Support I)
λ_I=0.1(Rate of I Actions)
μ_{GH}=0.1, μ_{BI}=0.1 <u>(Mean Time GH and BI Actions are Remembered=10)</u>
μ_{BH}=μ_{GI}=1 (Mean time BH and GI Actions are Remembered=1)
ξ_{GH}=ξ_{BH}=ξ_{GI}=ξ_{BI}=1

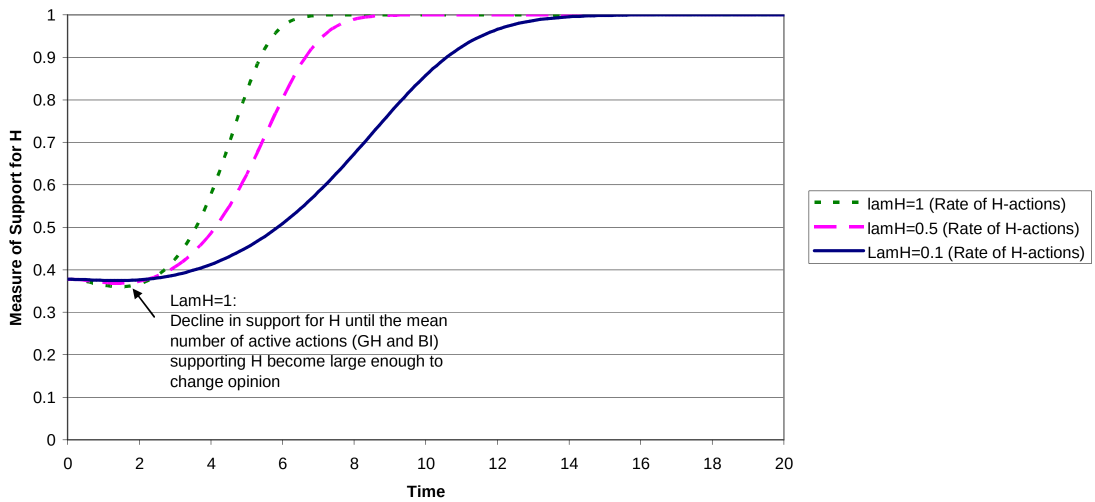

Figure 3c

Conclusions and Further Work

In this model each actor takes actions. These actions are perceived by the subpopulation as being good or bad. Each action has a positive duration during which it affects the attitude of subpopulations. These simple models suggest the changes in subpopulation attitude is a nonlinear function of the rate at which actions occur; the rate at which actions affect the subpopulation attitude; the mean time an action continues to influence attitudes; and the basic attitude the subpopulation has towards the actors.

In further work we will explore the model for more than one subpopulation. We will develop models to include the beliefs of the actors in relation to those of the subpopulations. We will also include more than one type of action for the actors.

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APPENDIX B: SOCIAL NETWORK MODEL NOTES

Notes on Influence Models for Dynamic Settings

1. First, there are several versions of what I will call the fundamental influence model in social systems. In its most basic state, we can say that an individual has an attitude or is likely to engage in a behavior as a function of several factors. These factors can be characterized as primarily attributes (age, sex, education, resources available to them, etc.) and social (influence from friends, contacts, competition, social comparisons, relative depravation, etc.). The first class of factors is traditionally characterized in the standard model as follows:

$$y_i = \mathbf{X}_{ik}\beta_k + \epsilon_i$$

where y_i is the variable of interest (attitude, behavior, performance) on the i subjects, X is a matrix of k explanatory attributes on the i "cases" (people), and ϵ_i is the error term. It is ordinarily assumed that ϵ is IID (the observations around each case are independent of each other), which, along with a few other reasonable assumptions, allows us to estimate the magnitude (β_k) and significance of the effect each of the k variables has on the dependent variable.

We know, however, that these observations are not independent of one another. Quite the contrary, we know that people influence each other on a daily basis. Social network models explicitly take into account such effects through a general model that takes the following form:

$$y_i = X_{ik}\beta_k + \rho_1 \mathbf{W}_{1_{ij}} y_j + \epsilon_i, \qquad \text{where } \epsilon\epsilon' \sim \rho_2 \mathbf{W}_{2_{ij}}$$

W is an ixj matrix that describes the extent to which each neighbor in the network affects each other actor. The $W_1 y$ term, then, is a vector of net direct effects of neighbors' attribute values on any given actor in the system. The W_2 term describes indirect effects in that it captures the extent to which actors' "errors" are not independent but rather autocorrelated (influenced by common sources not otherwise captured in the model).

Estimating these social equations requires going beyond standard econometric models

1

(although MLE solutions have been provided by Doreian, 1984). Friedkin and Johnsen (1999) add to this model a set of dynamics such that one can predict the evolution and equilibrium value of y over time.

Another possible way to look at this process of influence is to model it as a diffusion process. That is, ideas, values, beliefs, and behaviors, all change over time as the participants in the system influence each other to "agree" with them. Diffusion occurs to the extent to which the overall system moves from one set of states (beliefs, etc.) to another. The aforementioned Friedkin-Johnsen model is a reasonable and popular diffusion model.

Another interesting alternative model is the viscosity model (Krackhardt, 1997). It adds to the social influence process an assumption that those with new, innovative ideas will exhibit some enthusiasm for them and tend to proselytize more than those who are tied to the old ways. Formally, the viscosity model has two stages: First, subsets of individuals migrate at certain rates (viscosity rate) along network paths to interact with others in the network. Second, after migration takes place, they encounter new individuals, some proportion of which will "disagree" with their prior position or belief. If this proportion is high enough, they have a probability of converting to the other state (belief). These two stages are modeled as:

Stage 1: New beta (after migration, before adoption) = old beta - outflow + inflow

$$\beta^{t'} = \beta^{t-1} - \frac{[v\mathrm{W} \cdot \beta^{t-1}\mathbf{1}']\mathbf{1}}{\max[deg(\mathrm{W})]} + \frac{v\mathrm{W}\beta^{t-1}}{\max[deg(\mathrm{W})]}$$

where β is the vector of proportion of adopters for each group; v is the viscosity (visiting) rate of actors as they move from one group to an adjacent one; W is the network of possible migration paths for actors; and the $\max[deg(\mathrm{W})]$ function is a normalizing constant (maximum degree in W) which simply assures us that no migration exceeds the maximum possible.

Stage 2: Conversion rates:

At any time point t, we find the new proportion of adopters in group i (after migration and adoption) as follows:

$$\beta_i^t = \beta_i^{t'} - \sigma\beta_i^{t'}(1-\beta_i^{t'})^{L_a} + \tau(1-\beta_i^{t'})(\beta_i^{t'})^{L_n}$$

where σ is the rate at which adopters become non-adopters when they fail to find like-minded partners among the L_a searched, and τ is the rate at which non-adopters convert to adopters when they fail to find like-minded partners among the L_n searched.

The dynamics in this model are more complicated and have no tractable MLE solution, but results can be reliably obtained through monte carlo simulation. These models demonstrate how the shape and structure of the network itself can determine whether a new idea will successfully diffuse throughout the system.

Each model of network influence can have either a threshold "trigger", which converts an actor from one state to another (such as assumed in viscosity theory), or it can assume people gradually move from one attitude to another over a smooth scale. This deceptively mild assumption actually can make a difference in how the system behaves. Incorporating "many-to-other" (mass media, for example) influences also can make a difference, but these are not as profound.

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-David

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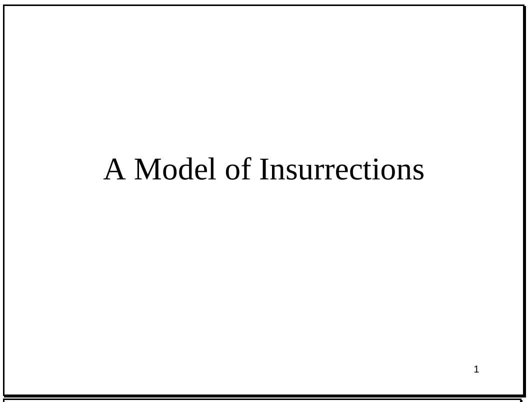
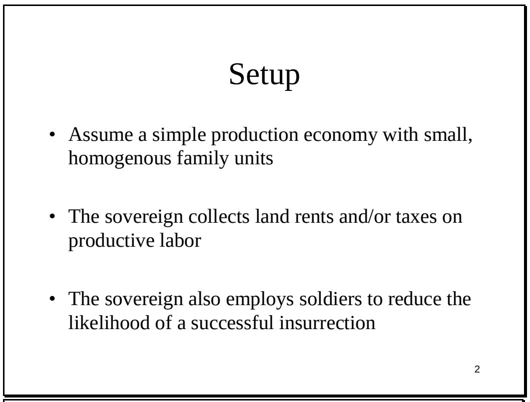
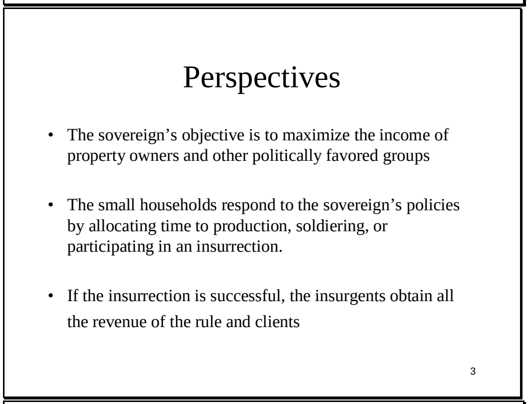
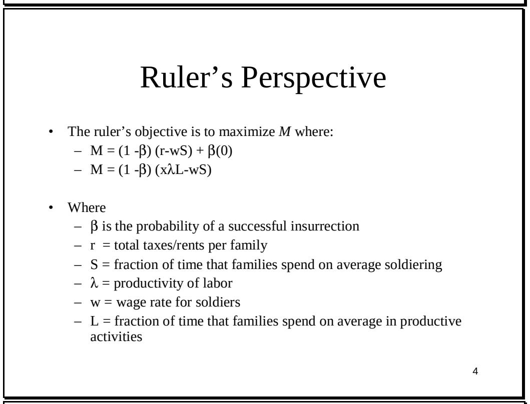
APPENDIX C: ECONOMIC INSURRECTION MODEL

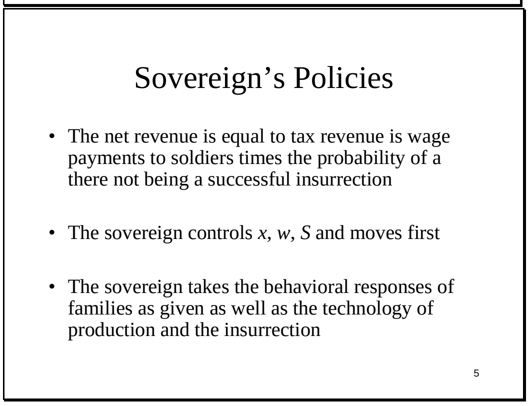
This PowerPoint presentation was provided to the TRAC-Monterey RUCG project by Professor McNab, NPS.[14]

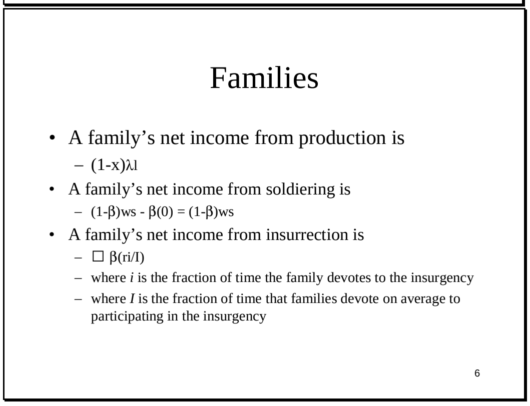












[14] Robert. M. McNabb, "A Model of Insurrections," 5 October 2007, at TRAC-Monterey, CA.

Family Income

- Each family takes x, λ, β, w, r, I as given
- Each family chooses l, s, i such that l+s+i = 1
- The expected income of a family is
  - $e(y) = (1-x)\lambda l + (1-\beta)ws + \beta(ri/I)$

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Allocating Time

- Allocation of time to production satisfies
  - $l = 0$ if $(1-x)\lambda l < \max[(1-\beta)w, \beta r/I]$
  - $l = [0,1]$ if $(1-x)\lambda l = \max[(1-\beta)w, \beta r/I]$
  - $l = 1$ if $(1-x)\lambda l > \max[(1-\beta)w, \beta r/I]$
- Allocation of time to soldiering satisfies
  - $s = 0$ if $w < \max[(1-x)\lambda l, \beta r/I]$
  - $s = [0,1]$ if $w = \max[(1-x)\lambda l, \beta r/I]$
  - $s = 1$ if $w > \max[(1-x)\lambda l, \beta r/I]$
- Allocation of time to insurrection satisfies
  - $i = 0$ if $\beta r/I < \max[(1-x)\lambda l, (1-\beta)w]$
  - $i = [0,1]$ if $\beta r/I = \max[(1-x)\lambda l, (1-\beta)w]$
  - $i = 1$ if $\beta r/I > \max[(1-x)\lambda l, (1-\beta)w]$

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Probability of Insurrection

- To model the likelihood of a successful insurrection, we assume that β is an increasing function of *I*, decreasing function of *S*
- Define $\beta = I^{1-\theta}/(s^{\sigma} + I^{1-\theta})$
  - θ and σ represent the technology of insurrection
  - β is larger the larger the θ and σ
- For I=.2, S=.2, $\theta = .2$ and $\sigma = .2$, $\beta = .28$
- For I=.2, S=.2, $\theta = .8$ and $\sigma = .2$, $\beta = .5$

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Elasticity

- We can obtain the elasticity of β with respect to *I* and σ to examine the percentage increase in soldiers needed to counteract the impact on β of a 1% increase in the size of the insurrection
- $e_{\beta,I} = (1-\theta)(1-\beta)$
- $e_{\beta,\sigma} = -\sigma(1-\beta)\ln s$
- If we assume that s is fixed, then $(1-\theta)/\sigma$ represents the percentage increase in *S* necessary to offset the influnece of a 1% increase in *I*

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Participating in the Insurrection

- Given $\beta = I^{1-\theta}/(s^{\sigma} + I^{1-\theta})$ and that $\beta r/I$ equals the returns from participating in the insurrection, we can find that
- $\beta r/I = (x\lambda l) / (s^{\sigma} + I^{1-\theta})$
- If x>0, L>0, I>0, S>0 then the expected return to insurgent activity is larger larger the θ and σ

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Sovereign's Objective

- Maximize $M = (1-\beta)(x\lambda L - wS)$
- Subject to:
  - $l = 0$ if $(1-x)\lambda l < \max[(1-\beta)w, \beta r/I]$
  - $l = [0,1]$ if $(1-x)\lambda l = \max[(1-\beta)w, \beta r/I]$
  - $l = 1$ if $(1-x)\lambda l > \max[(1-\beta)w, \beta r/I]$
  - $s = 0$ if $w < \max[(1-x)\lambda l, \beta r/I]$
  - $s = [0,1]$ if $w = \max[(1-x)\lambda l, \beta r/I]$
  - $s = 1$ if $w > \max[(1-x)\lambda l, \beta r/I]$
  - $i = 0$ if $\beta r/I < \max[(1-x)\lambda l, (1-\beta)w]$
  - $i = [0,1]$ if $\beta r/I = \max[(1-x)\lambda l, (1-\beta)w]$
  - $i = 1$ if $\beta r/I > \max[(1-x)\lambda l, (1-\beta)w]$
  - $\beta = I^{1-\theta}/(s^{\sigma} + I^{1-\theta})$

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Resulting Cases

- Case 1: (L,S,I) > (0,0,0)
  - $\partial M/\partial L = \partial M/\partial S = \partial M/\partial I$
- Case 2: (S,I) > 0, L =0
  - $\partial M/\partial L \le \partial M/\partial S = \partial M/\partial I$
  - If L = 0, then r = 0, then M = 0
- Case 3: (L,S) > 0, I = 0
  - $\partial M/\partial I \le \partial M/\partial S = \partial M/\partial M$
  - If $\theta > 0$, then when I=0, L>0, S>0, then $\beta r/I = \infty$ which violates the K-T conditions
- Case 4: (L,I) > 0, S = 0
  - $\partial M/\partial S \le \partial M/\partial I = \partial M/\partial M$
  - If I>0, L>0, S=0 then β=1 and M= 0

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Resulting Cases

- Case 5: L = 1, I=S=0
  - $\partial M/\partial S \le \partial M/\partial L \ge \partial M/\partial M$
  - If L=1, I=S=0, then then $\beta r/I = \infty$
- Case 6: I=1, L=S=0
  - $\partial M/\partial L \le \partial M/\partial I \ge \partial M/\partial S$
  - M=0
- Case 7: S=1, L=I=0
  - $\partial M/\partial L \le \partial M/\partial S \ge \partial M/\partial I$
  - M=0

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What Does This Mean?

- If case 1 is relevant, each and every family cannot chose l,s,i to be either 0 or 1
- If case 3 is relevant, each family chooses i=0 but cannot chose l,s = 0 or 1
- This implies that $(1-x)\lambda = (1-\beta)w$ and $(1-x)\lambda \geq \beta r/I$
- In other words, $(1-x)\lambda = (1-\beta)w$ implies that the expected returns from soldiering and production are equal
- $(1-x)\lambda \geq \beta r/I$ implies that if i>0 then the expected returns for l,s,i are equal

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Independence from λ

- Combining and taking the f.o.c's of
  - $M = (1-\beta)(x\lambda L-wS)$
  - $\beta = I^{1-\theta}/(s^{\sigma} + I^{1-\theta})$
  - $(1-x)\lambda = (1-\beta)w$
  - $(1-x)\lambda \geq \beta r/I$
- $\partial M/\partial L = [\lambda I/(1+\beta L)^2][(1-\beta)I- \beta S]$
- $\partial M/\partial S = [\lambda\beta I/(1+\beta L)][(\sigma(1-\beta)I)/(1+\beta L))-1]$
- $\partial M/\partial I \leq [x\beta L/(1+\beta L)^2][(1-\beta)L + S - (1-\theta)(1-\beta)]$
- β and x, w, s are independent of production technology

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Equilibrium

- Replace i, s, l with I, S, L to obtain
  - $E = (1-x)\lambda L + (1-\beta)wS + \beta x\lambda L$
- For either I = 0 or I > 0
  - $E = (1-x)\lambda$
- Adding E to the objective function yields:
  - $E + M = \lambda L$
- So each families expected share of total income should be:
  - $E/(E+M) = (1-x)/L$

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Spreadsheet

σ	θ	Λ	I	Σ	ξ	β	M/λ Client Income	E/λ	E/(M+E) Family Income
0.01	0.00	1.00	0.00	0.00	0.49	0.00	0.48	0.51	0.51
0.50	0.00	0.86	0.00	0.14	0.30	0.00	0.16	0.70	0.81
0.99	0.00	0.77	0.00	0.23	0.24	0.00	0.00	0.76	1.00
0.01	0.10	0.94	0.06	0.00	0.45	0.07	0.39	0.55	0.59
0.50	0.10	0.78	0.11	0.11	0.33	0.30	0.11	0.67	0.86
0.99	0.10	0.13	0.84	0.04	0.88	0.95	0.01	0.12	0.95
0.01	0.50	0.74	0.25	0.00	0.50	0.35	0.24	0.51	0.68
0.50	0.50	0.52	0.41	0.07	0.52	0.71	0.05	0.48	0.91
0.99	0.50	0.03	0.95	0.02	0.97	0.98	0.00	0.03	0.99
0.01	0.90	0.61	0.39	0.00	0.57	0.49	0.17	0.43	0.71
0.50	0.90	0.39	0.55	0.06	0.64	0.80	0.03	0.36	0.92
0.99	0.90	0.02	0.97	0.01	0.98	0.99	0.00	0.02	0.98

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GE Benefits

- For a given population, we can estimate the fractions of time devoted to the various activities
- We can explore through simulation the influence of technology on the incomes of the "household" and the sovereign's clients
- The model helps us explore how the policies of the sovereign affect the distribution of household effort

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Drawbacks

- Static GE model through some of the relationships may be endogenous
- Social networks are not defined as agents are assumed homogenous
- No spatial distribution

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Future

- Insurgency only wins or losses. What happens if insurgency results in loss of a percentage of income?
- What happens when risk of participating in soldiering or insurgency increases?
- What about specifying losses associated with various activities?

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Modifications

- Can we model a mechanism by which the reputation of the insurgent movement affects the fraction of time that households are willing to devote to the effort?
- Should we incorporate heterogeneity into the model?
- Complexity is nice, but at what cost..

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